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LECTURES

ON

NATURAL AND EXPERIMENTAL PHILOSOPHY,

CONSIDERED IN IT'S PRESENT STATE OF

IMPROVEMENT.

DESCRIBING, IN A FAMILIAR AND EASY MANNER,

THE PRINCIPAL PHENOMENA OF NATURE;

AND SHEWING,

THAT THEY ALL CO-OPERATE IN DISPLAYING

THE

GOODNESS, WISDOM, AND POWER OF GOD.

By GEORGE ADAMS,

Mathematical Inſtrument Maker to His Majeſty, and Optician to His Royal Highneſs the Prince of Wales.

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ERRATA.

Vol. 4, page 226, line 3, *for* 38 millions of miles, *read* 18,717,442,690,526 miles.

Page 296, line 12, *for* by *read* be.

LECTURES
ON
NATURAL PHILOSOPHY.

ON
ASTRONOMY.

LECTURE XXXVII.

Of the Copernican System.

HAVING ſhewn you the appearances of the heavenly bodies as ſeen from the earth, it will be now proper to ſhew you why the motions of the planets *appear* to us ſo different from what they *really* are. One of the ends for which man was formed, is to correct appearances and error by the inveſtigation of truth; whoever conſiders him attentively from infancy to manhood, and from manhood to old age, will find him ever buſy in endeavouring to find ſome reality to ſupply the place of thoſe falſe appearances, by which he has hitherto been deceived. Thus, it is the buſineſs of the preſent Lecture, to correct the errors that ariſe from appearances in the heavens, and to prove the truth

of the *Copernican Syſtem*, which is now generally received, becauſe it rationally accounts for, and accords with the phenomena of the heavens. In this ſyſtem, the ſun is placed in the center, and the earth and other planets revolve round him as their center.

There are, however, ſtrong reaſons for believing that ſome of the ſages of antiquity were acquainted with the true ſolar ſyſtem as revived by Copernicus. It was the univerſal doctrine of the Pythagorean ſchool, and is clearly marked out as ſuch by Ariſtotle: for theſe, ſays he, aſſert that fire is in the midſt of the world, and that the earth is one of the heavenly bodies. He afterwards ſpeaks of a ſet of men, who held a ſyſtem eſſentially ſimilar to that of the modern Semitychonic. Eudemus, in his hiſtory of aſtronomy, as cited by Anatolius, ſays, that Anaximander was the firſt who diſcovered the earth to be one of the heavenly bodies, and to move round the center of the world. Ariſtarchus held that the earth is carried round the ſun, in the circumference of a circle, of which the ſun itſelf is the center; and that the ſphere of the fixed ſtars is ſo immenſe, that the circle of the earth's annual orbit bears no greater proportion to it, than the center of any ſphere bears to it's whole ſurface. Philolaus, and others, declared the motion of the ſun, round about the earth, to be only apparent. They ſaw and felt the importance of his globe over our's, and ſuppoſing it's influence to extend to much larger bounds than that of the earth, they placed it in the center of the univerſe. Among the Romans, we find that Numa built a temple to repreſent, as Plutarch interprets it,* the ſyſtem of the

* Thoſe that want further information on this head, may conſult

the heavens, with a ſacred fire in the center of it.

Thus alſo in the Jewiſh tabernacle, the ſeven lights had a reference to the ſeven chief lights of the heavens. Hence alſo the heavens are called in ſacred writ the tabernacle of the ſun; the whole of our ſyſtem dwelling within his influence. The foregoing citations are, we preſume, ſufficient to ſhew that the ancients were not ignorant of the true ſolar ſyſtem.

But ſtill it was no general perſuaſion, nor does it ſeem ever to have been mentioned after the time of *Ptolemy*, who adopted that ſyſtem which now goes under his name; his ſyſtem, though erroneous, was ingenious; with it the world was content for many ages. It was then conſidered as founded upon invincible demonſtration; as a ſacred truth that could not be weakened by the powers of controverſy, or ſhaken by the fluctuations of opinion.

"But at the appointed time when it pleaſed the SUPREME DISPENSER of good gifts to reſtore light to a bewildered world, and more particularly to manifeſt his wiſdom in the ſimplicity as well as the grandeur of his works, he opened the ſcene with a revival of ſound aſtronomy.*

This obſervation of the *preſident of the Royal Society*, is well worthy your attention; it will open your views of DIVINE PROVIDENCE, which is a topic that ought to be ſet in every poſſible light that can make it either more clearly, or more generally underſtood. If you look through the hiſtory of paſt ages from the early periods of the paſ-

ſult the notes to Sydenham's tranſlation of the Rivals of Plato, Duten's Inquiries into the Origin of the Diſcoveries attributed to the Moderns; Jones's Eſſay on the firſt Principles of Natural Philoſophy; Baillie Hiſtoire de l'Aſtronomie ancienne.

* Sir John Pringle's Six Diſcourſes, p. 97.

toral and patriarchal life, you will fee arts and fciences progreffively advancing; fometimes *indeed buried for a long interval*, but again reviving with new fplendor. You fee philofophy and religion advancing, and though fometimes deformed by *fuperftition*, and unnatural fyftems of *atheifm*, yet fucceffively recovered from the dreams of the enthufiaft, and the fubtlety of the atheift. If you fee fcepticifm and infidelity making frequent attacks upon facred truths, you may reft fatisfied that thefe attempts will, in due time, magnify it's power, increafe it's honors, and advance it's triumphs.

There is no man but what, with refpect to the arts and improvements of life, looks back with pity on paft times, compared with his own; and philofophy never extended the province of human knowledge fo far and wide as within the laft century. It is thus alfo with divine knowledge; this has had the fame gradation and order of progreffion, *nature* and *law*, *type* and *fhadow*, the *fubftance* and the *archetype*; the kingdom of GOD is ftill advancing, and the evidences of his adminiftration and attributes ftill opening; every thing evinces that a grand defign has been carrying on from the earlieft account of hiftory by a remarkable courfe of Providence, for the benefit of the whole human race.

GOD pervades infinity, and fees through eternity; he fees the *child* not only as ftruggling with cries and tears, but he fees in the child the advancing and full grown man. While we fee partially and therefore imperfectly the fingle and unconnected, or perhaps only the loweft link of the extended and univerfal chain of being; GOD fees the whole and every part in their origin, their connection, their progreffion, and confummation.

From the fall to the prefent day, GOD has been working for our happinefs, in the only way proper

proper to display his goodness, and make us sensible of his mercies. He administers his blessings as we are able to bear them; HE is the fountain of eternal good, but we are not so capable of receiving as he is of communicating. As our powers are enlarged, and our nature refined, our pleasures will improve, and our happiness advance.*

The universe is the stage and theatre of God, carrying on the whole, and every part from greater to less perfection, and drawing in just proportion all the creatures to himself. Almighty goodness neither slumbers nor sleeps, but is ever labouring to advance our state; we are first brought into life, from life advance to reason, from reason to virtue, virtue to grace, and grace to glory.

It is *divine love* that through eternity is drawing order from confusion, raising harmony from seeming discord, building strength on weakness, and happiness on the misery of it's creatures. Love, eternal love, shines in the rudest as in the gayest, in the darkest as in the brightest scenes of nature, in the still small voice as in the thunder of

 almighty

* "The means which God vouchsafes to employ for the perfect overthrow of the Devil's kingdom, are not such as he might be expected to put in use, if his omnipotence were alone regarded; but they are such as are consistent with the free agency of man, and such as are adapted to the nature of man as a rational and moral agent; and adapted to the justice, and wisdom, and mercy of God in his dealings with such a creature."—"He abstains therefore from all summary, abrupt, coercive measures, and he employs no other means than those of persuasion and argument, invitation and threatening. It is very obvious, that ages must elapse before these means can produce their full effect; that the progress of the work will not only be gradual, but liable to temporary interruptions; insomuch, that it may at times seem to go backward as often as particular circumstances in the affairs of the world draw away the attention of men from the doctrine of the gospel, or rouse an extraordinary opposition of their passions to it's precepts." Bp. Horsley's Sermon for the Philanthropic Society, March 25, 1792.

almighty power; in the tempeſt as in the calm, in the horrors of winter as in the bloom of ſpring or plenty of autumn. Love, ſupreme love, is infinite and inexhauſtible, and we only queſtion the means becauſe we ſee not the end and conſummation of it's operations.*

Such are a *few* of the concluſions that may be deduced from a view of the advancement of arts and ſcience, and which we have been led naturally to conſider from ſeeing the long period that elapſed ere the Copernican ſyſtem was eſtabliſhed; and there is abundant reaſon to preſume, that the progreſſion obſervable and carried on from the beginning of time, will ſtill hold on, and know no other bounds than the fulneſs of the Godhead.

SUMMARY VIEW OF THE SOLAR SYSTEM.

I ſhall now proceed to give you a ſummary view of the ſolar ſyſtem, or that which was revived and drawn from oblivion by NICHOLAS COPERNICUS, about the year 1500. It is called the *ſolar ſyſtem*, becauſe the ſun is ſuppoſed to be fixed in the center, with our earth, and ſeveral bodies ſimilar thereto, revolving round him at different diſtances.

The *planets* are thoſe bodies within our ſyſtem that revolve round the ſun; they appear bright by reflecting the light they receive from the ſun, and are divided by aſtronomers into three kinds, *primary planets*, *ſecondary planets*, and *comets*.

The *primary planets* are thoſe bodies which in revolving round the ſun reſpect him only as the center of their courſes, the motions of which are regularly performed in tracks or paths that are found

* Hunter's Sermons on Divine Providence.

found to be *nearly* circular and concentric to each other.

A *ſecondary planet*, commonly called a *ſatellite* or *moon*, is a body, which, while it is carried round the ſun, does alſo revolve round a primary planet, which it reſpects as a center.

Comets are bodies, which are alſo ſuppoſed to revolve round the ſun; the planets appear *permanent* in the ſyſtem, but comets only occur *accidentally*: they are named comets from their being uſually attended with long tails, fancied by ſome to reſemble hair. The theory of their motions amounts at preſent to little better than *rude conjecture*.

The path deſcribed by a planet in it's motion round the ſun, is called it's *orbit*.

In ſpeaking of orbits, nothing more is meant than an imaginary circle defining the path they deſcribe, and in which they are retained by a celeſtial but continuous mechaniſm.

There are ſeven primary planets uſually reckoned in order from the ſun; their names and marks are,

Mercury.	Venus.	The Earth.	Mars.	Jupiter.	Saturn.	Georgium Sidus.
☿	♀	⊕	♂	♃	♄	♅

Mars, Jupiter, Saturn, and the Georgium Sidus, are called *ſuperior planets*, becauſe their orbits include that of the earth.

Venus and Mercury are called *inferior planets*, becauſe their orbits are contained within the earth's.

By the aſſiſtance of teleſcopes *ſecondary planets* have been diſcovered; the Earth is attended by one, Jupiter by four, Saturn by ſeven, and the Georgium Sidus by two.

This diagram (*pl.* 1, *fig.* 1, *Aſtronomy*,) repre-

ſents the ſolar ſyſtem, O in the center repreſents the ſun, AB the circle deſcribed by Mercury in moving round the ſun, CD that in which Venus moves, FG the orbit of the earth, HK that of Mars, IN that of Jupiter, OP the path of Saturn, QR the orbit of the Georgium Sidus.

Every primary planet is ſuppoſed to have two motions, 1. the *annual;* 2. the *diurnal.*

The ANNUAL MOTION of a planet is that whereby it is carried in it's orbit round the ſun, which in every one is found to be in the ſame direction from *weſt* to *eaſt.*

This motion, as you have ſeen, is diſcovered by the planets changing their places in the celeſtial ſphere, where they appear to move among the fixed ſtars; and in certain times to return to the ſame ſtars from which they were ſeen to depart, and ſo on continually.

The *diurnal motion* of a planet is that by which it turns or ſpins about it's axis; this like their annual motion is from *weſt* to *eaſt.*

This motion is diſcovered by the ſpots that are ſeen by teleſcopes on the ſurface of the planets; before the diſcovery of teleſcopes, it was not ſuſpected that the planets had a rotatory motion.

By continued obſervation, the ſpectator finds that theſe ſpots change their places, and move from one ſide of the planet to the other; then diſappear for a certain ſpace of time; after which, they again, for a while, become viſible on the ſide where they were firſt ſeen, always continuing the ſame motion nearly in an uniform manner. The diſtance betweeen the ſpots grow wider as they advance from the edge towards the middle of the planet, and then grows narrow again as they paſs from the middle to the other edge. The time they are ſeen on the planet's diſk, is ſomewhat leſs than the time

time of their diſappearance; they are firſt ſeen on the eaſtern margin of the planet, and diſappear on the weſtern ſide or *limb.*

From theſe circumſtances it is concluded, firſt, that theſe ſpots adhere to the body of the planet; and ſecondly, that each planet is a globe turning on it's axis.

It may not be improper to obſerve to you, that the axis of a planet is only an imaginary line conceived to be drawn through it's center, and about which it is conceived to turn in the courſe of it's revolution round the ſun. A ball whirled from the hand in the open air, turns round upon a line within itſelf, while it is moving forward; ſuch a line as this is meant when we ſpeak of the axis of a planet.

The ſun and moon, the ſtars and planets, appear to be all at an equal diſtance from us; though it is highly probable, that ſome of the ſtars are many millions of times nearer to us than others. The ſun is demonſtrated to be nearer than any of the ſtars. The moon and ſome of the planets are known by ocular proof to be nearer to us than the ſun, becauſe they ſometimes come between it and our eye, and hide the whole, or a great part of his diſk from our view. They all, however, appear equally diſtant, and as if placed in the ſurface of a ſphere, whereof our eye is the center. In whatever place, therefore, a ſpectator reſides, whether it be on this earth, in the ſun, or in the regions of Saturn, he will conſider that place as the center of the world; for it will be to him the center of a ſpherical ſurface, in which all diſtant bodies appear to be placed; for while he remains in the ſame place, he cannot judge properly of the diſtance of ſurrounding objects, at leaſt of thoſe which are placed beyond the ordinary reach of his view; for beyond that diſtance all the principles by which

we

we form our general judgment fail us, and we can only tell which is neareſt, or that which is furtheſt, by our own *motion*, or that of the objects.

To illuſtrate this, let us ſuppoſe a number of lamps to be placed irregularly at different diſtances from the eye in a dark night. Now, if in this caſe we ſuppoſe the darkneſs to be ſo complete that no intermediate objects can be ſeen, no difference in colour obſerved, nor any perception of a convergence toward the point of ſight, our judgment could not aſſiſt us in diſtinguiſhing the diſtance of one from the other; they would therefore all ſeem to be at an equal diſtance from the ſpectator.

Each planet is obſerved to paſs through the conſtellations, *Aries*, *Taurus*, *Gemini*, *Cancer*, *Leo*, *Virgo*, *Libra*, *Scorpio*, *Sagittarius*, *Capricornus*, *Aquarius*, *Piſces*; and it alſo appears, that every one has a track peculiar to itſelf, and that they never move out of a certain ſpace or zone of the heavens, which is called the *zodiac*.

By obſerving the planets in their periodic revolutions among the fixed ſtars, it is found that the paths of the planets are not all in the ſame plane, but they croſs each other in different parts of the heavens. As they thus move in planes that are differently inclined to each other, it became neceſſary to refer them all to one plane, in order both to judge more accurately of their inclination, and to avoid the intricacies of calculation; this plane thus became a ſtandard, and was conſidered as having no obliquity; all the reſt are referred thereto. For this purpoſe aſtronomers have fixed upon the *ecliptic* or orbit of the earth.

The *plane of the ecliptic* is ſuppoſed to divide the celeſtial ſphere into two equal parts, called the *northern and ſouthern celeſtial hemiſpheres*; and any body in either of theſe hemiſpheres, is ſaid to have north

north or ſouth latitude, according to the hemiſphere it is in. The *latitude* of a celeſtial object is it's neareſt diſtance from the ecliptic taken on the ſphere.

The planets are obſerved to be ſometimes on the northern and ſometimes on the ſouthern ſide of the ecliptic, ſo that their reſpective planes cut the ecliptic in two oppoſite points called *nodes;* or, in other words, the *nodes* of a planet's orbit are the two points where it interſects the ecliptic. Thus, let A B C D, *fig.* 3, *pl.* 3, repreſent the ecliptic, B E D F the orbit of a planet, the points B and D are the two nodes.

One is called the *aſcending node*, and is uſually marked thus ☊; it is that through which the planet paſſes when it moves out of the ſouthern into the northern hemiſphere. The other node through which the planet paſſes in going out of the northern into the ſouthern hemiſphere, is called the deſcending node, marked thus ☋.

During therefore every revolution, each planet muſt deſcribe half it's orbit above the plane of the ecliptic, the other half below. They have therefore a north latitude, while they deſcribe one half of their orbit; and a ſouth latitude, while they deſcribe the other half.

The ſeveral orbits do not croſs the ecliptic at the ſame point, or with the ſame angles; their nodes are at different parts of the ecliptic.

A right line joining the two nodes of any planet, is called the *line of the nodes.*

The line of the nodes paſſes through the ſun, for as the motion of every planet is in a plane paſſing through the ſun, conſequently the interſection of theſe planes, that is, the line of the nodes, muſt alſo paſs through the ſun.

You may render the inclination of the planet's orbits to each other familiar to your mind, by taking

ing as many hoops as there are planets, with a wire thruſt through each, and thereby joined to that hoop which repreſents the ecliptic, and you may then ſet the other hoops more or leſs obliquely to the repreſentative of the ecliptic.

I before mentioned to you that the planets revolved round the ſun in orbits nearly circular and concentric, for their ſeveral phenomena ſhew that they are not ſtrictly ſo. And aſtronomers have found, that the only curve they can move in to reconcile all the various appearances is an *ellipſis*, ſo that the orbits of the primary planets are ellipſes of different curvatures, having one common focus in which the ſun is fixed; but every ſecondary planet reſpects the primary planet, round which it revolves as the focus of it's elliptic motion.

To deſcribe an *ellipſis*, let a thread, tied together at both ends, be put over two pins fixed upright upon a plane, at any diſtance from each other leſs than the ſtring thus tied will reach, a pen carried round within the ſtring ſo as to keep it always ſtretched out with the ſame tenſion, will deſcribe upon the plane a curve, which is the periphery or circumference of an ellipſis. Either of the points S, N, *fig.* 4, *pl.* 3, where the pins are fixed in the plane, is called the focus of the ellipſis. The further the foci are from one another, the more oblong will the ellipſis deſcribed with the thread be. The nearer the foci are to each other, the nearer will the ellipſis be to a circle.

A line P A, *fig.* 4, *pl.* 3, drawn through the foci both ways till it reaches the circumference, is called the axis, and the greater axis or longeſt diameter. A point C taken in this line equally diſtant from either of the foci, is called the center of the ellipſis. A line T V drawn through the center perpendicular to the longeſt diameter, till it reaches the

the circumference both ways, is called the leffer axis, or fhorteft diameter. The diftance between the center and either of the foci, C N or C S, is the excentricity of the ellipfis, which is greater or lefs, as the ellipfis is more or lefs oblong.

The orbit of every planet is an ellipfis, having the fun in one of it's foci. The axis P A of any planet's ellipfis, is called the line of the apfides; the point A, where the planet is at it's greateft diftance from the fun, is it's *aphelion*, or higher apfis; the point P where it is at it's leaft diftance from the fun, it's *perihelion*, or lower apfis; the extreme points of the fhorteft diameter T V are the places of it's middle or mean diftance from the fun. A line S T or S V drawn from either of thofe points to the fun, is the line of it's mean diftance. To eftimate the excentricity of any planet, we fuppofe the line of it's mean diftance S T to be divided into 1000 equal parts, and fay the excentricity is fuch a number of thofe parts.

The motion of the planets in their orbits is not equable; but every planet obferves this rule, that a line drawn from the fun to the planet fweeps equal areas upon the plane of it's ellipfis in equal times; therefore every planet moves fwifteft in it's *perihelion*, or floweft in it's *aphelion*, with a middle or mean motion at it's mean diftance.

Thus in the figure, A is the place of the aphelion, P the place of the perihelion, P A the line of apfides, P A is the tranfverfe diameter of the ellipfes, T V the conjugate diameter.

The *mean diftance* of a planet from the fun, is it's diftance from him when the planet is at either extremity of the conjugate diameter, and is equal to half the tranfverfe diameter.

When two planets are feen together in the fame fign equally advanced, they are faid to be in con-

conjunction; but when they are in direct oppoſite parts of the zodiac, they are ſaid to be in *oppoſition*.

The place that any planet appears to occupy in the celeſtial hemiſphere, when ſeen by an obſerver ſuppoſed to be placed in the ſun, is called it's *heliocentric* place, it's heliocentric latitude, &c.

The place it occupies when ſeen from the earth, is called it's *geocentric* place, &c.

A motion in the heavens in the order of the ſigns, as from Aries to Taurus, &c. is ſaid to be *in conſequentia*, and ſuch are the real motions of all the planets, though their apparent motions are ſometimes contrary, and then they are ſaid to move *in antecedentia*.

The points where the celeſtial equator cuts the ecliptic are found to have a motion in *antecedentia* of about fifty ſeconds every year. This change of place of the firſt point of the ecliptic, from whence the ſigns are counted, occaſions a like change in the ſigns themſelves, which, though ſcarce ſenſible for a few years, has now become very conſiderable. Thus, ſince the time that aſtronomy was cultivated by the Greeks, that is, about 2000 years ago, the firſt point of the ecliptic is removed backward about a whole ſign; and though it was then about the middle of the conſtellation Aries, it is now about the middle of Piſces. Notwithſtanding this alteration, the ſigns ſtill retain their ancient names and marks.

The longitude of a phenomenon in the heavens is the number of degrees counted from the firſt point of Aries on the ecliptic, to the place where a circle of latitude drawn through the phenomenon would cut the ecliptic at right angles.

Thus every phenomenon in the heavens is referred to the *ecliptic* by the circles of latitude, as the

the longitudes of terreſtrial places are referred to the equator by the meridians; and whatever ſign the circle of latitude paſſes through, the phenomenon is ſaid to have it's place in that ſign.

OF THE FIGURE AND LIGHT OF THE PLANETS.

That the ſun and planets are *ſpherical* bodies, is evident from all the obſervations that have been made on them; and that the earth is of the ſame figure, is not only deducible from analogy, but it is alſo proved by obſervation, as I ſhall ſhew in the proceſs of theſe Lectures. Aſtronomers, when they ſay that the planets are ſpherical bodies, do not mean a geometrical ſphere, but a figure called an *oblate ſpheroid*, which is ſomething like the figure that a flexible ſphere would be formed into by gently preſſing it at it's poles. Obſervations have determined this in Jupiter, and it is known that the earth is of this figure, both from obſervation and actual menſuration.

That the planets are all *opake*, or dark bodies, and conſequently ſhine only by the light they receive from the ſun, is plain, becauſe they are not viſible when they are in ſuch parts of their orbits as are between the ſun and earth, that is, when their illuminated ſide is turned from us.

The ſun enlightens only half a planet at once; the illuminated hemiſphere is always that which is turned towards the ſun, the other hemiſphere of the planet is dark. To ſpeak with accuracy, the ſun being larger than any of the planets, will illuminate rather more than half; but this difference, on account of the great diſtance of the ſun from any of the planets, is ſo ſmall, that it's light may be conſidered as coming to them in lines phyſically parallel.

Like

Like other opake bodies, they caſt a ſhadow behind them, which is always oppoſite to the ſun. The line in the planet's body, which diſtinguiſhes the lucid from the obſcure part, appears ſometimes ſtrait, ſometimes crooked. The convex part of the curve is ſometimes towards the ſplendid, and the concave towards that which is obſcure; and *vice verſa*, according to the ſituation of the eye with reſpect to the planet, and of the ſun which enlightens the planet.

OF THE SUN.

The ſun is the center of the ſyſtem, round which the reſt of the planets revolve. It is the firſt and greateſt object of aſtronomical knowledge, and is alone enough to ſtamp a value on the ſcience to which the ſtudy of it belongs. The ſun is the parent of the ſeaſons; day and night, ſummer and winter, are among it's ſurpriſing effects. All the vegetable creation are the offspring of it's beams; our own lives are ſupported by it's influence. Nature revives, and puts on a new face, when it approaches nearer to us in ſpring; and ſinks into a temporary death at his departure from us in the winter.

Hence it was with propriety called by the ancients *cor cœli*, the heart of heaven; for as the heart is the center of the animal ſyſtem, ſo is the ſun the center of our univerſe. As the heart is the fountain of the blood, and the center of heat and motion; ſo is the ſun the life and heat of the world, and firſt mover of the mundane ſyſtem. When the heart ceaſes to beat, the circuit of life is at an end; and if the ſun ſhould ceaſe to act, a total ſtagnation would take place throughout the whole frame of nature.

"By

"By his magnetic beam he gently warms
The univerſe, and to each inward part,
With gentle penetration, though unſeen,
Shoots inviſible virtue."

The ſun is placed near the center of the orbits of all the planets, and turns round his axis in 25 1/4 days. It is inclined to the ecliptic in an angle of eight degrees. His apparent diameter, at a mean diſtance from the earth, is about thirty-two minutes, twelve ſeconds.

Thoſe who are not accuſtomed to aſtronomical calculation, will be ſurprized at the real magnitude of this luminary; which, on account of it's diſtance from us, appears to the eye not much larger than the moon, which is only an attendant on our earth. When looking at the ſun, you are viewing a globe, whoſe diameter is above 890,000 Engliſh miles; whereas the earth is not more in diameter than 7970 miles: ſo that the ſun is about 1,392,500 times bigger than the earth. As it is the fountain of light and heat to all the planets, ſo it alſo far ſurpaſſes them in it's bulk. In proportion as ſcience has advanced, and more accurate inſtruments have been made, the magnitude of this luminary has been found to exceed conſiderably the limits of former calculations.

If the ſun were every where equally bright, his rotation on his axis would not be perceptible; but by means of the ſpots, which are viſible on his pure and lucid ſurface, we are enabled to diſcover this motion.

When a ſpherical body is near enough to appear of it's true figure, this appearance is owing to the ſhading upon the different parts of it's ſurface: for as a flat circular piece of board, when it is properly ſhaded by painting will look like a ſpherical body; ſo a ſpherical body appears of it's true ſhape,

ſhape, for the ſame reaſon that the plane board, in the preſent inſtance, appears ſpherical. But if the ſphere be at a great diſtance, this difference of ſhading cannot be diſcerned by the eye, and conſequently the ſphere will no longer appear of it's true ſhape, the ſhading is then loſt, and it ſeems like a flat circle.

It is thus with the ſun; it appears to us like a bright flat circle, which flat circle is termed the *ſun's diſk*. By the aſſiſtance of teleſcopes, dark ſpots have been obſerved on this diſk, and found to have a motion from eaſt to weſt; their velocity is greater when they are at the center, than when they are near the limb. They are ſeen firſt on the eaſtern extremity, by degrees they come forwards towards the middle, and ſo paſs on till they reach the weſtern edge; they then diſappear; and after they have lain hid about the ſame time that they continued viſible, they will appear again as at firſt. By this motion we diſcover not only the time the ſun employs in turning round his axis, but alſo the inclination of it's axis to the plane of the ecliptic.*

The page of hiſtory informs us, that there have been periods, when the ſun has wanted of it's accuſtomed brightneſs, ſhone with a dim and obſcure light for the ſpace of a whole year. This obſcurity has been ſuppoſed to ariſe from his ſurface being at thoſe times covered with ſpots. Spots have been ſeen that were much larger than the earth.

The ſun is ſuppoſed to have an atmoſphere round

* The obſerver may view the ſpots of the ſun with a refracting teleſcope of two or three feet, or a reflecting one of 12 inches, 18 inches, or two feet, taking care to guard the eye with a dark glaſs, to take off the glaring light; or the image or picture of the ſun, with his ſpots, may be thrown into a dark room, through a teleſcope, and received upon a piece of paper placed nearer or further from the glaſs at pleaſure.

round it, which occaſions that appearance which is termed the *zodiacal light*. This light is ſeen at ſome ſeaſons of the year, either a little after ſun-ſet, or a little before ſun-riſe. It is faintly bright, and of a whitiſh colour, reſembling the milky way. In the morning it becomes brighter and larger, as it riſes above the horizon, till the approach of day, which diminiſhes it's ſplendor, and renders it at laſt inviſible. It's figure is that of a flat or lenticular ſpheroid, ſeen in profile. The direction of it's longer axis coincides with the plane of the ſun's equator. But it's length is ſubject to great variation, ſo that the diſtance of it's ſummit from the ſun varies from 45 to 120 degrees. It is ſeen to the beſt advantage about the ſolſtices. It was firſt deſcribed and named by Caſſini, in 1683; it was noticed by Mr. Childrey, about the year 1650.

OF THE INFERIOR PLANETS, MERCURY AND VENUS.

OF MERCURY. ☿

Of all the planets, Mercury is the leaſt; at the ſame time, it is that which is neareſt the ſun. It is from his proximity to this globe of light, that he is ſo ſeldom within the ſphere of our obſervation, being loſt in the ſplendor of the ſolar brightneſs, yet it emits a very bright white light. It is oftener ſeen in thoſe parts of the world, which are more ſouthward than that which we inhabit; and oftener to us than to thoſe who live nearer the north pole; for the more oblique the ſphere is, the leſs is the planet's elevation above the horizon.

Mercury never removes but a few degrees from the ſun. The meaſure of a planet's ſeparation, or diſtance, from the ſun, is called it's *elongation*. His greateſt elongation is little more than twenty-eight degrees, or about as far as the moon appears to be from the ſun, the ſecond day after new moon. In ſome of it's revolutions, the elongation is not more than eighteen degrees.

Mercury is computed to be at about 37 millions of miles from the ſun, and to revolve round him in 87 days, 23 hours, and nearly 16 minutes, which is the meaſure of it's year, about one-fourth of our's. As from the nearneſs of this planet to the ſun, we neither know the time it revolves round it's axis, nor the inclination of that axis to the plane of it's orbit, we are neceſſarily ignorant of the length of it's day and night, or the variety of ſeaſons it may be liable to. Mercury is 3000 miles in diameter, and therefore contains in ſurface 28,274,400 ſquare miles. Large as Mercury, when thus conſidered, appears to be, it is but an atom, when compared with Jupiter, whoſe diameter is 90,000 miles. It's apparent diameter, at a mean diſtance from the earth, is 20 ſeconds.

Mercury is ſuppoſed to move at the rate of 110,680 miles per hour. The ſun is above 26,000,000 times as big as Mercury; ſo that it would appear to the inhabitants of Mercury nearly three times larger than it does to us; and it's diſk, or face, about ſeven times the ſize we ſee it. As the other five planets are above Mercury, their phenomena will be nearly the ſame to it as to us. Venus and the earth, when in oppoſition to the ſun, will ſhine with full orbs, and afford a brilliant appearance to the Mercurian ſpectator.

Mercury, like the moon, changes it's phaſes, according to it's ſeveral poſitions, with reſpect to the

the ſun and earth. He never appears quite round or full to us, becauſe his enlightened ſide is never turned directly towards us, except when he is ſo near the ſun, as to become inviſible. The times for making the moſt favourable obſervations on this planet, are, when it paſſes before the ſun, and is ſeen traverſing his diſk, in the form of a black ſpot. This paſſage of a planet over the face of the ſun, is called a *tranſit*. It happens in it's lower conjunction, at a particular ſituation of the nodes.

If Mercury, at his inferior conjunction, comes to either of his nodes about theſe times, he will appear to *tranſit* over the diſk of the ſun. But in all other parts of his orbit his conjunctions are inviſible, becauſe he either goes above or below the ſun.

OF VENUS. ♀

Venus is the brighteſt and largeſt, to appearance, of all the planets, diſtinguiſhed from them all by a ſuperiority of luſtre: her light is of a white colour, and ſo conſiderable, that in a duſky place ſhe projects a ſenſible ſhade.

The diameter of Venus is 7,699 Engliſh miles; her diſtance from the ſun is about 69,500,000 miles; ſhe goes round the ſun in 224 days, 6 hours, 49 minutes, moving at the rate of 80,955 miles per hour. Her motion round her axis has been fixed by ſome at 23 hours, 22 minutes; by others at above 24 days. She, like Mercury, conſtantly attends the ſun, never departing from him above 47 or 48 degrees. Like Mercury, ſhe is never ſeen *at midnight, or in oppoſition to the ſun,* being viſible only for three or four hours in the morning, or evening, according as ſhe is before or after the ſun.

One would not imagine that this planet, which appears ſo much ſuperior to Saturn in the heavens, is ſo inconſiderable when compared to it; for the diameter of Saturn is 79,979 miles; while, on the other hand, one would ſcarce imagine that Venus, which appears but as a lucid ſpangle in the heavens, was ſo large a globe as ſhe truly is, her diameter being 7,699 miles. It is the diſtance which produces theſe effects; which gives and takes away the magnitude of things. Her apparent ſize varies with her diſtance; at ſome ſeaſons ſhe appears nearly 32 times larger than at others.

When this planet is in that part of it's orbit which is weſt of the ſun, that is, from her inferior to her ſuperior conjunction, ſhe riſes before him in the morning, and is called *phoſphorus*, or *lucifer*, or the *morning ſtar*. When ſhe appears eaſt of the ſun, that is, from her ſuperior to her inferior conjunction, ſhe ſets in the evening after him; or in other words, ſhines in the evening after he ſets, and is called *heſperus*, or *veſper*, or the *evening ſtar*.

The inhabitants of Venus will ſee the planet Mercury always accompanying the ſun; and he will be to them, by turns, an evening or a morning ſtar, as Venus is to us. To the ſame inhabitants, the ſun will appear almoſt twice as large as he does to us.

Venus, when viewed through a teleſcope, is ſeldom ſeen to ſhine with a full face; but has phaſes, juſt like the moon, from the fine thin creſcent to the enlightened hemiſphere. Her illuminated part is conſtantly turned towards the ſun; hence it's horns are turned towards the eaſt when it is a morning ſtar, and towards the weſt when it is an evening ſtar. Some aſtronomers have thought they perceived a ſatellite moving round Venus; but

but as ſucceeding obſervers have not been able to verify their obſervations, they are ſuppoſed to have originated in error. In obſerving the tranſit of Venus, Mr. Dunn, and other gentlemen, ſaw a penumbra which took place about five ſeconds before the contact, preceding the egreſs of the planet; and from thence they coucluded, that it had an atmoſphere of about 50 geographical miles in height.

We are told, that, when Copernicus firſt publiſhed his account of the ſolar ſyſtem, it was objected to him that it could not be true, becauſe if it was, the inferior planets muſt have different phaſes, according to their different ſituation with reſpect to the ſun and earth; whereas they always appear round to us. The anſwer ſaid to be made by him, is, that they appear round to the eye by reaſon of their diſtance; but if we could have a nearer, or more diſtinct view of them, we ſhould ſee in them the ſame phaſes we do in the moon. The invention of teleſcopes is ſaid to have verified this prediction of Copernicus. But it is neither probable, that a defender of the Ptolemaic ſyſtem ſhould make ſuch an objection, or Copernicus ſuch an anſwer; ſince in the Ptolemaic, as well as in the Copernican ſyſtem, the ſhape of theſe planets ought to change, juſt as the moon does; conſequently, *the mere change of ſhape* in the inferior planets is an argument, which, in the common way of urging it, *proves nothing at all* as to the truth or falſhood of the Copernican ſyſtem. If, beſides the changes of ſhape made in the inferior planets, we conſider the ſituation of the planets with reſpect to the ſun, when theſe changes happen; this, indeed, will ſhew us, that the Ptolemaic ſyſtem is falſe, as will be ſeen in a ſubſequent part of theſe Lectures.

Taking the times in which the planets move round the ſun, for the length of their year; and the times of their turning round their axes, for the length of their days and nights together; and aſſuming, as true, the obſervations of Bianchini, relative to the rotation of Venus round her axis; we may ſay, that a day and a night in Venus is as long as 23 ½ days and nights with us; her axis inclines 75 degrees from the axis of her orbit, on which account the length of her days and nights differs much more in proportion, and the variation of her ſeaſons is greater than thoſe of our earth. She very ſeldom has the forenoon and afternoon of the ſame day of an equal length. At her equator ſhe has the four ſeaſons twice every year, with other peculiarities, which are enumerated in larger treatiſes on this ſubject.

Venus is ſometimes ſeen paſſing over the diſk of the ſun, as a round dark ſpot. Theſe appearances, which are called tranſits, happen very ſeldom; though there have been two within theſe few years, the one in June, 1761, the other in June, 1769; the next will be in the year 1874.

OF THE EARTH. ⊕

The next planet that comes before us is the earth that we inhabit; ſmall as it really is when compared to ſome of the other planets, it is to us of the higheſt importance: we wiſh only to attain knowledge of others, that we may find out their relation to this, and from thence learn our connection with the univerſe at large. But when viewed with an eye to eternity, it's value to us is heightened in a manner that exceeds expreſſion, and ſurpaſſes all the powers of the human mind. He alone can form ſome idea of it, who in the regions of

of celeſtial bliſs is become a partaker of the length and breadth, the depth and height, of divine love.

The orbit of the earth is placed between thoſe of Venus and Mars. The diameter of the earth is 7920 miles; it's diſtance from the ſun is nearly 96 millions of miles, and it goes round him in a year, moving at the rate of 68,856 miles per hour. It's apparent diameter, as ſeen from the ſun, is about twenty-one ſeconds.

It turns round it's axis, from weſt to eaſt, in twenty-four hours, which occaſions the apparent diurnal motion of the ſun, and all the heavenly bodies round it, from eaſt to weſt, in the ſame time; it is, of courſe, the cauſe of their riſing and ſetting, of day and night.

The axis of the earth is inclined $23\frac{1}{2}$ degrees to the plane of it's orbit, and keeps in a direction parallel to itſelf, throughout it's annual courſe, which cauſes the returns of ſpring and ſummer, autumn and winter. Thus it's diurnal motion gives us the grateful viciſſitude of night and day, and it's annual motion the regular ſucceſſion of ſeaſons.

Of the Moon. ☾

Next to the ſun, the moon is the moſt ſplendid and ſhining globe in the heavens, the ſatellite, or inſeparable companion of the earth. By diſſipating, in ſome meaſure, the darkneſs and horrors of the night; ſubdividing the year into months; and regulating the flux and reflux of the ſea; ſhe not only becomes a pleaſing, but a welcome object; an object affording much for ſpeculation to the contemplative mind, of real uſe to the navigator, the traveller, and the huſbandman. The Hebrews,

Hebrews, the Greeks, the Romans, and, in general, all the ancients used to assemble at the time of new moon, to discharge the duties of piety and gratitude for it's manifold uses.

That the moon appears so much larger than the other planets, is owing to her vicinity to us; for to a spectator in the sun she would be scarcely visible, without the assistance of a telescope. Her distance is but small from us, when compared with that of the other heavenly bodies; for among these, the least absolute distance, when put down in numbers, will appear great, and the smallest magnitude immense.

The moon is 2161 miles in diameter; her bulk is about three-elevenths of the earth; her distance from the center of the earth 240,000 miles; she goes round her orbit in 27 days, 7 hours, 43 minutes, moving at the rate of 2299 miles per hour. The time in going round the earth, reckoning from change to change, is 29 days, 12 hours, 44 minutes. Her apparent diameter at a mean distance from the earth, is 31 minutes 16 seconds; but as viewed from the sun, at a mean distance about 6 seconds.

Her orbit is inclined to the ecliptic, in an angle of 5 degrees, 18 minutes, cutting it in two points, which are diametrically opposite to each other; these points are called her nodes. The nodes have a motion westward, or contrary to the order of the signs, making a complete revolution in about nineteen years; in which time, each node returns to that point of the ecliptic whence it before receded.

If the moon were a body possessing native light, we should not perceive any diversity of appearance; but as she shines entirely by light received from the sun, and reflected by her surface, it follows, that according to the situation of the beholder

beholder with respect to the illuminated part, he will see more or less of her reflected beams; for only one half of a globe can be enlightened at once.

Hence, while she is making her revolution round the heavens, she undergoes great changes in her appearance. She is sometimes on our meridian at midnight, and therefore in that part of the heavens which is opposite to the sun; in this situation she appears as a complete circle, and it is said to be *full moon*. As she moves eastward, she becomes deficient on the west side, and in about $7\frac{1}{3}$ days comes to the meridian, at about six in the morning, having the appearance of a semicircle, with the convex side turned towards the sun; in this state, her appearance is called the *half moon*. Moving on still eastward, she becomes more deficient on the west, and has the form of a crescent, with the convex side turned towards the sun; this crescent becomes continually more slender, till about fourteen days after the full moon she is so near the sun, that she cannot be seen, on account of his great splendor. About four days after this disappearance, she is seen in the evening, a little to the eastward of the sun, in the form of a fine crescent, with the convex side turned from the sun; moving still to the eastward, the crescent becomes more full; and when the moon comes to the meridian, about six in the evening, she has again the appearance of a bright semicircle; advancing still to the eastward, she becomes fuller on the east side; at last, in about $29\frac{1}{2}$ days, she is again opposite to the sun, and again full.

It frequently happens, that the moon is eclipsed when at the full; and that the sun is eclipsed some time between the disappearance of the moon in the morning on the west side of the sun, and her appearance in the evening on the east side of the

the ſun. The nature of theſe phenomena will be more fully conſidered, when we come to treat particularly of eclipſes.

In every revolution of the moon about the earth, ſhe turns once round upon her axis, and therefore always preſents the ſame face to our view; and as, during her courſe round the earth, the ſun enlightens ſucceſſively every part of her globe only once, conſequently ſhe has but one day in all that time, and her day and night together are as long as our lunar month. As we ſee only one ſide of the moon, we are therefore inviſible to the inhabitants on the oppoſite ſide, without they take a journey to that ſide which is next to us, for which purpoſe ſome of them muſt travel more than 1500 miles.

As the moon illuminates the earth by a light reflected from the ſun, ſhe is reciprocally enlightened, but in a much greater degree, by the earth; for the ſurface is above thirteen times greater than that of the moon; and therefore, ſuppoſing their power of reflecting light to be equal, the earth will reflect thirteen times more light on the moon than ſhe receives from it. When it is what we call new moon, we ſhall appear as a full moon to the Lunarians; as it increaſes in light to us, our's will decreaſe to them: in a word, our earth will exhibit to them the ſame phaſes as ſhe does to us.

We have already obſerved, that from one half of the moon the earth is never ſeen; from the middle of the other half, it is always ſeen over head, turning round almoſt thirty times as quick as the moon does. To her inhabitants, the earth ſeems to be the largeſt body in the univerſe, about thirteen times as large to them, as ſhe does to us. As the earth turns round it's axis, the ſeveral continents and iſlands appear to the Lunarians

as

as ſo many ſpots, of different forms; by theſe ſpots, they may determine the time of the earth's diurnal motion; by theſe ſpots, they may, perhaps, meaſure their time,—they cannot have a better dial.

OF THE SUPERIOR PLANETS.

Mars, Jupiter, Saturn, and the Georgium Sidus, are called ſuperior planets, becauſe they are higher in the ſyſtem, or farther from the center of it, than the earth is.

They exhibit ſeveral phenomena, which are very different from thoſe of Mercury and Venus; among other things, they come to our meridian both at noon and midnight, and are never ſeen croſſing the ſun's diſk.

OF MARS. ♂

Mars is the leaſt bright and elegant of all the planets; it's orbit lies between that of the earth and Jupiter, but very diſtant from both. He appears of a duſky reddiſh hue; from the dullneſs of his appearance, many have conjectured that he is encompaſſed with a thick cloudy atmoſphere; his light is not near ſo bright as that of Venus, though he is ſometimes nearly equal to her in ſize.

Mars, which appears ſo inconſiderable in the heavens, is 5,309 miles in diameter. It's diſtance from the ſun is about 146,000,000 miles. It goes round the ſun in 1 year, 321 days, 23 hours, moving at the rate of 55,287 miles per hour. It revolves round it's axis in 24 hours, 39 minutes. To an inhabitant in Mars, the ſun would appear one-

third

third leſs in diameter than it does to us. It's apparent diameter, as viewed at a mean diſtance from the earth, is 30 ſeconds.

Mars, when in oppoſition to the ſun, is five times nearer to us than when in conjunction. This has a very viſible effect on the appearance of the planet, cauſing him to appear much larger at ſome periods than at others.

The analogy between Mars and the earth is by far the greateſt in the whole ſolar ſyſtem; their diurnal motion is nearly the ſame; the obliquities of their reſpective ecliptics not very different. Of all the ſuperior planets, that of Mars is by far the neareſt like the earth: nor will the Martial year appear ſo diſſimilar to our's, when we compare it with the long duration of the years of Jupiter, Saturn, and the Georgium Sidus. It probably has a conſiderable atmoſphere; for beſides the permanent ſpots on it's ſurface, Dr. Herſchel has often perceived occaſional changes of partial bright belts, and alſo once a darkiſh one in a pretty high latitude; alterations which we can attribute to no other cauſe than the variable diſpoſition of clouds and vapours floating in the atmoſphere of the planet.

A ſpectator in Mars will rarely, if ever, ſee Mercury, except when they ſee it paſſing over the ſun's diſk. Venus will appear to him at about the ſame diſtance from the ſun, as Mercury appears to us. The earth will appear about the ſize of Venus, and never above 48 degrees from the ſun; and will be, by turns, a morning and evening ſtar to the inhabitants of Mars. It appears, from the moſt accurate obſervations, that Mars is a ſpheroid, or flatted ſphere, the equatorial diameter to the polar being in the proportion of about 131 to 127; and there is reaſon to ſuppoſe, that all the planets are of this figure.

OF

OF JUPITER. ♃

Jupiter is ſituated ſtill higher in the ſyſtem, revolving round the ſun, between Mars and Saturn. It is the largeſt of all the planets, and eaſily diſtinguiſhed from them by his peculiar magnitude and light. To the naked eye it appears almoſt as large as Venus, but not altogether ſo bright.

Jupiter revolves round it's axis in 9 hours, 56 minutes; it's revolution in it's orbit to the ſame point of the ecliptic is 11 years, 314 days, 10 hours. The diſproportion of Jupiter to the earth, in ſize, is very great; viewing him in the heavens, we conſider him as ſmall in magnitude; whereas he is in reality 90,228 miles in diameter. His diſtance from the ſun is 499,750,000 miles; he moves at the rate of rather more than 29,083 miles per hour. His apparent diameter, as ſeen at a mean diſtance from the earth, is 39 ſeconds.

To an eye placed in Jupiter, the ſun would not be a fifth part of the ſize he appears to us, and his diſk be 25 times leſs. Though Jupiter be the largeſt of all the planets, yet his revolution round his axis is the ſwifteſt. The polar axis is ſhorter than the equatorial one, and his axis perpendicular to the plane of his orbit.

Jupiter, when in oppoſition to the ſun, is much nearer the earth, than when he is in conjunction with him; at thoſe times he appears alſo larger, and more luminous than at other times.

In Jupiter, the days and nights are of an equal length, each being about five hours long. We have already obſerved, that the axis of his diurnal rotation is nearly at right angles to the plane of his annual one, and conſequently there can be ſcarce any difference in ſeaſons; and here, as far

as we may reafon from analogy, we may difcover the footfteps of wifdom: for if the axis of this planet were inclined by any confiderable number of degrees, juft fo many degrees round each pole would, in their turn, be almoft fix years in darknefs; and as Jupiter is of fuch an amazing fize, in this cafe immenfe regions of land would be uninhabitable.

Jupiter is attended by four fatellites, or moons; thefe are invifible to the naked eye; but through a telefcope they make a beautiful appearance. As our moon turns round the earth, enlightening the nights, by reflecting the light fhe receives from the fun, fo thefe alfo enlighten the nights of Jupiter, and move round him in different periods of time, proportioned to their feveral diftances: and as the moon keeps company with the earth in it's annual revolution round the fun; fo thefe accompany Jupiter in his courfe round that luminary.

In fpeaking of the fatellites, we diftinguifh them according to their places, into the firft, the fecond, and fo on; by the firft, we mean that which is neareft to the planet.

The outermoft of Jupiter's fatellites will appear almoft as big as the moon does to us; five times the diameter, and twenty-five times the difk of the fun. The four fatellites muft afford a pleafing fpectacle to the inhabitants of Jupiter; for fometimes they will rife all together, fometimes be all together on the meridian, ranged one under another, befides frequent eclipfes. Notwithftanding the diftance of Jupiter and his fatellites from us, the eclipfes thereof are of confiderable ufe, for afcertaining with accuracy the longitude of places. From the four fatellites the inhabitants of Jupiter will have four different kinds of months, and the number of them in their year not lefs than 4,500

An

An aſtronomer in Jupiter will never ſee Mercury, Venus, the Earth, or Mars; becauſe, from the immenſe diſtance at which he is placed, they muſt appear to accompany the ſun, and riſe and ſet with him: but then he will have for the objects of obſervation, his own four moons, Saturn, his ring and ſatellites, and probably the Georgium Sidus.

Of Saturn. ♄

Before the diſcovery of the Georgium Sidus, Saturn was reckoned the moſt remote planet in our ſyſtem; he ſhines but with a pale feeble light, leſs bright than Jupiter, though leſs ruddy than Mars. The uninformed eye imagines not, when it is directed to this little ſpeck of light, that it is viewing a large and glorious globe, one of the moſt ſtupendous of the planets, whoſe diameter is 79,979 miles. We need not, however, be ſurpriſed at the vaſt bulk of Saturn, and it's diſproportion to it's appearance in the heavens; for we are to conſider, that all objects decreaſe in their apparent magnitude, in proportion to their diſtance; but the diſtance of Saturn is immenſe; that of the earth from the ſun is 96,000,000 miles; of Saturn, 916,500,000 miles!

The length of a planet's year, or the time of it's revolution round it's orbit, is proportioned to it's diſtance from the ſun. Saturn goes round the ſun in 29 years, 167 days, 6 hours, moving at the rate of rather more than 22,298 miles per hour. His apparent diameter at a mean diſtance from the earth is 16 ſeconds.

It has not yet been aſcertained by aſtronomical obſervation, whether Saturn revolves or not upon his axis: we are therefore ignorant of the

length of his day, and of his night. The ſun's diſk will appear ninety times leſs to an inhabitant of Saturn than it does to us; but notwithſtanding the ſun appears ſo ſmall to the inhabitants of the regions of Jupiter and Saturn, the light that he will afford them is much more than would be at firſt ſuppoſed; and calculations have been made, from which it is inferred, that the ſun will afford 500 times as much light to Saturn, as the full moon to us; and 1600 times as much to Jupiter. To eyes like our's, unaſſiſted by inſtruments, Jupiter and the Georgium Sidus would be the only planets ſeen from Saturn, to whom Jupiter would ſometimes be a morning, ſometimes an evening ſtar.

One of the firſt diſcoveries of the teleſcope, when brought to a tolerable degree of perfection, was, that Saturn did not appear like other planets. Galileo, in 1610, ſuppoſed it compoſed of 3 ſtars, or globes, a larger in the middle, and a ſmaller on each ſide; and he continued his obſervations till the two leſſer ſtars diſappeared, and this planet looked like the others. Further obſervation ſhewed, that what Galileo took for two ſtars, were parts of a ring. This ſingular and curious appendage to the planet Saturn, is a thin, broad, opake ring, encompaſſing the body of the planet, without touching it, like the horizon of an artificial globe, appearing double when viewed through a good teleſcope. The ſpace between the ring and the globe of Saturn, is ſuppoſed to be rather more than the breadth of the ring; the plane of the ring is inclined to the plane of the ecliptic, in an angle of 30 degrees, and is about 21,000 miles in breadth. It puts on different appearances to us, ſometimes being ſeen quite open, at others only as a line upon the equator. It is probable that it at times caſts a ſhadow over vaſt regions of Saturn's body. This

ring

ring ſuſpended round the body of the planet, and keeping it's place without any connection with the body, is quite different from all other planetary phenomena with which we are acquainted. But this is rendered ſtill more ſurpriſing by the diſcoveries of Dr. Herſchel, who finds that the planet Saturn *has two concentric rings*, of unequal dimenſions and breadth ſituated in one plane, which is probably not much inclined to the equator of the planet. Theſe rings are at a conſiderable diſtance from each other, the ſmalleſt being much leſs in diameter at the outſide, than the largeſt is at the inſide; the two rings are entirely detached from each other, ſo as plainly to permit the open heavens to be ſeen through the vacancy between them. Of the nature of this ring, various and uncertain were the conjectures of the firſt obſervers; though not more perplexed, than thoſe of the lateſt. Of it's uſe to the inhabitants of Saturn, we are as ignorant as of it's nature.

Saturn is not only furniſhed with this beautiful ring, but it has alſo ſeven attendant moons.

Of the Georgium Sidus. ♅

From the time of Huygens and Caſſini, to the diſcovery of the Georgium Sidus by Dr. Herſchel, though the intervening ſpace was long, though the number of aſtronomers was increaſed, though aſſiduity in obſerving was aſſiſted by accuracy and perfection in the inſtruments of obſervation, yet no new diſcovery was made in the heavens, the boundaries of our ſyſtem were not enlarged. The inquiſitive mind naturally inquires, why, when the number of thoſe that cul-

tivated the ſcience was increaſed, when the ſcience itſelf was ſo much improved, in practical diſcoveries it was ſo deficient? A ſmall knowledge of the human mind will anſwer the queſtion, and obviate the difficulty. The mind of man has a natural propenſity to indolence; the ardour of it's purſuits, when they are unconnected with ſelfiſh views, are ſoon abated, ſmall difficulties diſcourage, little inconveniences fatigue it, and reaſon ſoon finds excuſes to juſtify, and even applaud this weakneſs. In the preſent inſtance, the unmanageable length of the teleſcopes that were in uſe, and the continual expoſure to the cold air of the night, were the difficulties the aſtronomer had to encounter with; and he ſoon perſuaded himſelf, that the ſame effects would be produced by ſhorter teleſcopes, with equal magnifying power; herein was his miſtake, and hence the reaſon why ſo few diſcoveries have been made ſince the time of Caſſini. A ſimilar inſtance of the retrogradation of ſcience occurs in the hiſtory of the microſcope, as I have ſhewn in my eſſays on that inſtrument.

The Georgium Sidus was diſcovered by Dr. Herſchel, in the year 1781; for this diſcovery he obtained, from the Royal Society, the honorary recompence of Sir Godfrey Copley's medal. He named the planet in honour of his Majeſty King George III. the patron of ſcience, who has taken Dr. Herſchel under his patronage, and granted him an annual ſalary. By this munificence he has given ſcope to a very uncommon genius, and enabled him to proſecute his favourite ſtudies with unremitted ardour.

In ſo recent a diſcovery of a planet ſo diſtant, many particulars cannot be expected. It's year is ſuppoſed to be more than 80 years; it's diameter

34,299

34,299 miles; diſtance from the ſun about 1,832 millions of miles; the inclination of it's orbit 43 degrees 35 ſeconds; it's diameter, compared to that of the earth, as 431,769 to 1; in bulk it is 8,049,256 times as large as the earth. It's light is of a blueiſh white colour, and it's brilliancy between that of the moon and Venus.

Though the Georgium Sidus was not known as a planet till the time of Dr. Herſchel, yet there are many reaſons to ſuppoſe it had been ſeen before, but had then been conſidered as a fixed ſtar. Dr. Herſchel's attention was firſt engaged by the ſteadineſs of it's light; this induced him to apply higher magnifying powers to his teleſcope, which increaſed the diameter of it: in two days he obſerved that it's place was changed; he then concluded it was a comet; but in a little time he, with others, determined that it was a planet, from it's vicinity to the ecliptic, the direction of it's motion, being ſtationary in the time, and in ſuch circumſtances as correſpond with ſimilar appearances in other planets.

With a teleſcope, which magnifies about 300 times, it appears to have a very well-defined viſible diſk; but with inſtruments of a ſmaller power it can hardly be diſtinguiſhed from a fixed ſtar between the ſixth and ſeventh magnitude. When the moon is abſent, it may alſo be ſeen by the naked eye.

Dr. Herſchel has ſince diſcovered, that it is attended by two ſatellites: a diſcovery which gave him conſiderable pleaſure, as the little ſecondary planets ſeemed to give a dignity to the primary one, and raiſe it into a more conſpicuous ſituation among the great bodies of our ſolar ſyſtem.

As the diſtances of the planets, when marked in

in miles, are a burden to the memory, aſtronomers often expreſs their mean diſtances in a ſhorter way, by ſuppoſing the diſtance of the earth from the ſun to be divided into ten parts. Mercury may then be eſtimated at four of ſuch parts from the ſun, Venus at ſeven, the earth at ten, Mars at fifteen, Jupiter at fifty-two ſuch parts, Saturn at ninety-five, and the Georgium Sidus 190 parts.

TABLES

TABLES OF THE DIAMETERS, DISTANCES, &c. OF THE PLANETS.

Accompanied with various comparifons, in order to render the ideas of thefe diftances, &c. clearer to the mind.

When you endeavour to form any idea of diftance, magnitude, or duration, by numbers only, you foon exceed the limits of conception, and find your faculties of reafoning as finite as your fenfes. Hence aftronomers are frequently obliged to have recourfe to mixed ideas, and make things of different nature and properties affift each other, to excite more adequate ideas of what they would have expreffed. Some of thefe methods I fhall now lay before you, to affift your imagination in forming it's ideas of the vaft diftances and fizes of the planets.

	Diameters in Englifh miles.	In diam. of the earth.	Proportion of furface with refpect to the earth.	Proportion of bulk with refpect to the earth.
Sun -	893,522	113	12,719	1,434,400
Mercury	3,261	$\frac{2}{5}$	$\frac{1}{6}$	$\frac{1}{14}$
Venus -	7,699	$\frac{32}{33}$	near 1	$\frac{9}{10}$
Earth -	7,920	1	1	1
Moon -	2,161	$\frac{3}{11}$	above $\frac{1}{13}$	$\frac{1}{50}$
Mars -	5,312	$\frac{2}{3}$	$\frac{4}{9}$	$\frac{3}{16}$
Jupiter -	90,255	11 $\frac{1}{3}$	129 $\frac{3}{4}$	1,479
Saturn -	80,012	10	102	1,030
Georgium Sidus	34,217	4 $\frac{1}{3}$	18 $\frac{3}{4}$	81 $\frac{1}{9}$

MEAN DISTANCES IN MILLIONS OF MILES.

The distances being very great, the nearest million only is inserted, that it may be easier remembered.

Distances from the Sun.	Millions of miles.	Difference between the greatest & least distance of the sun from the earth in millions of miles.
Sun -		3
Mercury -	37 $\frac{1}{5}$	74 $\frac{4}{10}$
Venus -	69 $\frac{1}{2}$	139
Earth -	96	0
Moon -	96	33,570 miles.
		Millions.
Mars -	146 $\frac{1}{3}$	192
Jupiter -	499 $\frac{3}{4}$	192
Saturn -	916 $\frac{1}{2}$	192
Georg. Sid.	1,832	192

PERIODS ROUND THE SUN ACCORDING TO OUR YEARS AND MONTHS.

	years.	days.	hours.	min.	sec.	Progressive motion in their orbit miles per hour.
Mercury -	—	87	23	15	37	110,680
Venus -	—	224	16	49	12	80,955
Earth -	—	365	5	48	45	68,856
Mars -	—	686	23	30	63	55,783
Jupiter -	11	314	12	—	—	30,193
Saturn -	29	167	5	—	—	22,298
Georgium Sidus	80	—	—	—	—	16,411

	days.	hours.	min.	
Moon's periodical revolution round the earth	27	7	43	2,299
Synodical revol. or from change to change	29	12	44	

The

The following table from Mr. Vince's plan of a Courfe of Lectures, may be confidered as more accurate; it is deduced from M. de la Lande's work.

	mean dift.	Sid. Rev.				Nod. in 1750				Incl. 1786.			Aphelia 1750.			
		d.	h.	′	″	s.	°.	′	″	°	′	″	s.	°.	′	″
Mercury	38710	87	23	15	14	1	15	20	43	7	0	0	8	13	33	58
Venus -	72333	224	16	49	11	2	14	26	18	3	23	35	10	7	46	42
Earth -	100000	365	6	9	12								3	8	39	34
Mars -	152369	686	23	30	36	1	17	38	38	1	51	0	5	1	28	14
Jupiter -	520279	4332	14	27	11	3	7	55	32	1	18	56	6	10	21	4
Saturn -	954072	10759	1	51	11	3	21	32	22	2	29	50	8	28	9	7
Geor. Sidus	1.908180	83yr. 157d. 18h.				3	12	33	31	0	46	20	11	17	6	44

Revolution on it's own axis according to our days.					Motion on it's axis, miles per hour.
	days.	h.	min.		
Sun -	25	6			3,957
Mercury	unknown.				unknown.
Venus -		23	22		1,065
Earth -		23	56	4	1,042
Mars -		24	39		556
Jupiter -		9	56		25,920
Saturn -	unknown.				unknown.
Georgium Sidus	unknown.				unknown.
Moon -	27	7	43		near 10½

The rotation of Saturn, agreeable to Dr. Ufher's computations, is 10 hours, 12½ minutes. A different refult was, however, obtained, by taking the denfity of Saturn, as ftated by M. de la Lande. Dr. Herfchel has fettled the rotation of Saturn's ring at 10 hours, 32 minutes, 16 feconds.

Light

	Light and heat in proportion to what the earth receives.	Appearance of the sun in proportion to what it appears on the earth.
Mercury	7 times more	7 times greater
Venus -	double	twice as great
Earth -	1	1
Mars -	half	half as big
Jupiter -	one 27th.	one 27th.
Saturn -	one 91	one 91
Georg. Sid.	one 364th.	one 364th
Moon -	1	1

Sun's apparent diameter, 1 min. 41 sec.

DISTANCES AND APPARENT DIAMETERS OF THE SUN AND PLANETS.

	Distances from the Earth.			Appar. Diam. viewed from the Earth.					
	Greatest. mill. of miles	Least. mill. of miles.	Mean. mill. of miles.	Greatest ′	″	Least. ′	″	Mean. ′	″
Sun -	97 ½	94 ½	96	32	38	31	34	32	5
Mercury	133 ⅕	58 ⅘	96	0	11	0	5	0	7
Venus -	165 ½	26 ½	96	1	0	0	10	0	17
Earth -	0	0	0	0	0	0	0	0	0
Mars -	242 ⅓	50 ⅓	146 ⅓	0	22	0	4	0	7
Jupiter -	595 ¾	403 ¾	499 ¾	0	46	0	31	0	37
Saturn -	1.012 ½	820 ½	916 ½	0	18	0	14	0	37
Georg. Sid.	1.928	1736	1832	0.3.9		03.9		0	16
	miles.	miles.	miles.						3.9
Moon -	256.785	223.211	240 000	33.36		28.55.30		31	15

It has been found, that a cannon-ball moves about 8 miles in one minute, 704 feet in a second; and that sound moves about 13 miles in one minute, 1144 feet in a second.

A very high wind may make sound move one mile

mile in 4' seconds, 4 dec. that is, in about one-twentieth less time than in calm weather.

The most violent storm does not move above 1 mile in a minute, 88 feet in a second.

From hence it has been computed, that a body issuing from the sun, with the swiftness of a cannon-ball, that is, 8 miles in a minute, would employ the following time in reaching.

	years	months	days	hours	min.
Mercury - - -	8	10	6	13	18
Venus - - -	16	6	8	20	58
Earth - - -	22	10	4	21	20
Mars - - - -	34	9	19	16	35
Jupiter - - -	118	9	8	16	40
Saturn - - -	217	10	2	19	16
Georgium Sidus -	435	4	24	0	40
Any fixed star that has been accurately observed	7,600,000				

A ray of light comes from the sun to the earth in 8 min. 13 sec. moves therefore 11,693,462 miles in one minute, 194,891 miles in one second.

A ray of light comes from the moon in 1 second, 23 dec.

From the very accurate observations of Dr. Bradley, it is inferred, that no fixed star of the great numbers observed by him, can be at a less distance from the earth than about 400,000 distances of the sun from the earth; so that a ray of light, which comes to the earth in eight minutes, thirteen seconds, issuing from such a star, must require 6 years and 3 months to reach the earth.

The

The following may therefore be conſidered as proportionable diſtances of the celeſtial bodies from the ſun.

Mercury -	28 yards.
Venus - -	52 yards.
Earth - -	79 ditto.
Mars - -	109 ditto.
Jupiter -	273 ditto.
Saturn - -	684 ditto.
Georg. Sidus	1357 miles.

Moon 6 $\frac{1}{2}$ inches from the earth, Syrius 8410 miles.

PROPORTIONAL MAGNITUDE.

Sun - -	2 feet in diameter.
Mercury -	$\frac{1}{11}$ of an inch.
Venus -	$\frac{1}{7}$ of an inch.
Earth - -	$\frac{1}{5}$ $\frac{1}{100}$.
Mars - -	$\frac{1}{15}$ of an inch.
Jupiter -	2$\frac{1}{4}$ inches.
Saturn - -	2$\frac{1}{10}$ inches.
Georg. Sidus	about 1 inch.

The diſtance of Syrius is 18,717,442,690,526 miles. A cannon-ball going at the rate of 19.05 miles per minute, would only reach it in about 1,868,307 years, 88 days, 24 hours. The circumference of it's orbit is 117605162638454; if the ſtar moved through this ſpace in 24 hours, it muſt go 361170863 $\frac{3}{4}$ miles per ſecond.

Such is the immenſe diſtance even of a ſtar of the firſt magnitude, that, ſuppoſing the world to have exiſted 6000 years, and the diſtance to be reduced to 311 $\frac{1}{3}$, or 311.333 inches, or 25 feet 11 inches, then a cannon-ball, going at the rate of 1143 miles

miles per hour, and set in motion at the creation of the world, would now have passed only *one* inch of that reduced space; because *one* inch bears the same proportion to 311.3 as the distance which the ball would go in 6000 years does to the whole distance of the star. So,

If a cannon-ball goes 1 inch in 6000 years, how far will it go in 1868307?—Answer, 311.333, or 25 feet, 11 inches. Or,

If a cannon-ball goes 1871744269052б miles in 1868307 years, how far will it go in 6000?—Ans. 60110386645, which number is to 18717, &c. as 1 inch is to 311.333.

By the same rule, if we suppose a star of the second, third, tenth, one-hundredth magnitude, it's distance will be proportionably great, and the space gone through proportionably small; that is, in the same time the ball would have gone only one-half, one-third, one-tenth, one hundredth of an inch. With respect to a star of the third magnitude, it would now have passed through a space = one barley corn; with respect to one of the four-hundredth, not the space corresponding to *one* hair's breadth, reckoning 400 hairs = one inch.

This supposes that a star of the third, tenth, four-hundredth magnitude, is 3, 10, 400 times as distant as one of the first; and we may also suppose that a star which cannot be seen but with a power of 100, 1000, &c. is 100 and 1000 times more distant than one which the naked eye can just discover.

The distance of a star of the second magnitude is 37434885381053 ½ miles; the diameter of it's orbit = 74869770762107.

The circumference of it's orbit 235210325-276908.7; a degree of this is 653362014658; a minute, 10889366910.75; a second, 181489448 ½. A cannon-ball would require 65216 years, 86 days,

 6 hours,

6 hours, 17 minutes, 13 ſeconds, to go through one degree of this orbit; 1086 years, 342 days, 2 hours, 30 minutes, 17 ſeconds, to paſs through one *minute*; and 18 years, 42 days, 4 hours, 50 minutes, 30 ſeconds, to go over one *ſecond* of it.

The diſtance between δ and ε in Orion's belt, is 1 degree, 23 minutes, 12 ſeconds.

	°	′	″
Between ε and ζ - -	1	21	9
Between δ and ζ - -	2	44	21

Now taking the whole years, and neglecting the fractions of the above numbers 652161086, &c. 18; a cannon-ball would be 90410 years in paſſing from δ to ε, 88184 in going from ε to ζ, and 178594 from δ to ζ.

So likewiſe the diſtance between α and β, *urſa major*, or the two hind wheels of the *placeſtrum*, is 5° 23 miles, 20 ſeconds, which a cannon-ball would require 351418 years to paſs over.

This evidently ſuppoſes, that all ſtars of equal magnitude are equally diſtant, (not that this is certain, or even probable; but ſome data muſt be aſſumed,) and though not accurate, equally ſhew the wonders of God's creation.

The diameter of the earth being 7.920 miles, the ſurface in round numbers may be called 200 millions of ſquare miles.

		Millions.	
The ſurface -		200	Of that 40, America is 14, about $\frac{1}{3}$; Aſia 11, about $\frac{1}{4}$; Africa 10, $\frac{1}{4}$; Europe not 5, not $\frac{1}{8}$.
Whereof the ſea occupies	$\frac{4}{5}$	160	
The land - -	$\frac{1}{5}$	40	

Place

Place of the nodes for 1750.	ſign.	deg.	min.	ſec.	Annual motion of the nodes. min.	ſec.
Mercury	1	15	20	43	7	0
Venus -	2	14	26	18	19	2
Mars -	1	17	38	38	22	2
Jupiter -	3	7	55	32	14	5
Saturn -	3	21	32	22	16	9
Georg. Sid.	3	12	33	31		

Inclination of the orbits.			
Mercury -	7	0	0
Venus -	3	23	35
Mars -	1	51	0
Jupiter -	1	18	56
Saturn -	2	19	50
Georg. Sid.	0	46	20

I ſhall conclude this general ſurvey of the ſolar ſyſtem in the words of that excellent mathematician, Mr. Maclaurin. The view of nature, which is the immediate object of ſenſe, is very imperfect, and of ſmall extent; but by the aſſiſtance of art, and the aid of reaſon, becomes enlarged, till it loſes itſelf in infinity. As magnitude of every ſort, abſtractedly conſidered, is capable of being increaſed to infinity, and is alſo diviſible without end; ſo we find, that in nature the limits of the greateſt and leaſt dimenſions of things are actually placed at an immenſe diſtance from each other.

"We can perceive no bounds of the vaſt expanſe, in which natural cauſes operate, and fix no limit, or termination, to the univerſe. The objects we commonly call great, vaniſh, when we contemplate the vaſt body of the earth. The terraqueous globe itſelf is loſt in the ſolar ſyſtem; the ſun itſelf dwindles into a ſtar; Saturn's vaſt orbit, and all the orbits of the comets, crowd into a point, when viewed from numberleſs places between the

earth and the neareſt fixed ſtars. Other ſuns kindle to illuminate other ſyſtems, where our ſun's rays are unperceived; but they alſo are ſwallowed up in the vaſt expanſe. When we have riſen ſo high, as to leave all definite meaſures far behind us, we find ourſelves no nearer to a term, or limit.

"Our views of nature, however imperfect, ſerve to repreſent to us, in a moſt ſenſible manner, that mighty power which prevails throughout, acting with a force and efficacy that ſuffers no diminution from the greateſt diſtances of ſpace or intervals of time; and to prove that all things are ordered by infinite wiſdom, and perfect goodneſs. Scenes which ſhould excite and animate us to correſpond with the general harmony of nature."

LECTURE

LECTURE XXXVIII.

Explanation of the Seasons, and other Phenomena, on the Copernican System.

I AM now going to conſider the earth as a *planet*, having already given you an outline of the ſolar ſyſtem, of which the ſun is the center, with the ſeven planetary globes revolving in their reſpective orbits around him. The earth we inhabit is one of theſe ſeven revolving planets, and completes it's revolution in 365 days, 5 hours, 49 minutes, which conſtitutes our year; for it is by this progreſſion or annual motion of the earth, that our year is meaſured. But beſides this, in the ſpace of 24 hours it makes one complete revolution on it's axis, by which motion day and night are alternately occaſioned all over the world. To explain the phenomena on theſe principles, and to remove objections and difficulties, will be the ſubject of this Lecture; and, firſt of all, it will be neceſſary to prove to you the globular form of our earth.

Of the Shape or Figure of the Earth.

I have already obſerved, that the appearance of the heavenly bodies is not the ſame to the inhabitants of various parts of the earth; that the ſun, the moon, and the ſtars, riſe and ſet in Greenland in a manner very different from what they do in the Eaſt Indies, and in both places very different from what they do in England: and as it was na-

tural to attribute the cauſe of this change in the apparent face of the heavens, to the *figure of the earth*, (for appearances muſt ever anſwer to the form and ſtructure of the things,) the nature of this figure was, therefore, one of the firſt objects of inquiry among philoſophers and aſtronomers.

Some ſages of antiquity concluded, that the earth muſt neceſſarily be of a ſpherical figure, becauſe that figure was, on many accounts, the moſt convenient for the earth, as an habitable world: they alſo argued, that this figure was the moſt natural, becauſe any body expoſed to forces, which tend to one common center, as is the caſe with the earth, would neceſſarily aſſume a round figure. The aſſent, however, of the modern aſtronomers to this truth, was not determined by ſpeculative reaſoning; but on evidence, derived from facts and actual obſervation. From theſe I ſhall ſelect thoſe arguments, that I think will have the greateſt weight.

It is known, from the laws of optics and perſpective, that if any body, in all ſituations, and under all circumſtances, projects a *circular ſhadow*, that body muſt be a globe.

It is alſo known, that eclipſes of the moon are cauſed by the ſhadow of the earth.

And we find, that whether the ſhadow be projected towards the eaſt or the weſt, the north or the ſouth, under every circumſtance *it is circular*; the body, therefore, that caſts the ſhadow, which is the earth, muſt be of a *globular* figure.

You will obtain another convincing proof of the globular ſhape of the earth, by inquiring in what manner a perſon ſtanding upon the coaſt of the ſea, and waiting for a veſſel which he knows is to arrive, ſees that veſſel. We ſhall find, that he firſt of all, and at the greateſt diſtance, ſees the top of the maſt riſing out of the water; and the appearance

pearance is, as if the ſhip was ſwallowed up in the water. As he continues to obſerve the object, more and more of the maſt appears; at length he begins to ſee the top of the deck, and by degrees the whole body of the veſſel. On the other hand, if the ſhip be departing from us, we firſt loſe ſight of the hull, at a greater diſtance the main-ſails diſappear, and at a ſtill greater the top-ſail. But if the ſurface of the ſea were a plane, the body of the ſhip, being the largeſt part of it, would be ſeen firſt, and from the greateſt diſtance, and the maſts would not be viſible till it came nearer.

To render this, if poſſible, ſtill clearer, let us conſider two ſhips meeting at ſea, the top-maſt of each are the parts firſt diſcovered by both, the hull, &c. being concealed by the convexity of the globe which riſes between them. The ſhips may, in this inſtance, be reſembled to two men, who approach each other on the oppoſite ſides of a hill; their heads will be firſt ſeen, and gradually, as they approach, the body will come entirely in view. From hence is derived a rational method of eſtimating the diſtance of a ſhip, which is in uſe among ſea-faring people, namely, of obſerving, HOW LOW THEY CAN BRING HER DOWN; that is to ſay, the man at the maſt-head fixes his eyes on the veſſel in ſight, and ſlowly deſcends by the ſhrowds, till ſhe becomes no longer viſible. The leſs the diſtance, the lower he may deſcend before ſhe diſappears. If obſervations of this kind be made with a teleſcope, the effect is ſtill more remarkable; as the diſtance increaſes or diminiſhes, the ſhip in ſight will appear to become more and more immerſed, or to riſe gradually out of the water.

This truth is alſo fully evinced by the following conſideration; that ſhips have ſailed round the earth, have gone out to the weſtward, and have

come home from the eaſtward; or in other words, the ſhips have kept the ſame courſe, and yet returned from the oppoſite ſide into the harbour whence they firſt ſailed. Now we are certain that this could not be the caſe, if the earth were a plane; for then a perſon, who ſhould ſet out for any one point, and go on ſtrait forward, without ſtopping, would be continually going further from the point from which he ſet out.

Fig. 1 and 2, *pl*, 2, are illuſtrations of the foregoing principles. *Fig.* 1, ſhews that if the earth was a plane, the whole of a ſhip would be ſeen at once, however diſtant from the ſpectator, and that, whether he be placed at the top or bottom of a hill. From *fig.* 2, it appears, that the rotundity of the earth, repreſented by the circle A B C, conceals the lower part of the ſhip *d*, while the top-maſt is ſtill viſible; and that it is not till the ſhip comes to *e* that the whole of it is viſible.

The following remarks evince the ſame truth. Obſerve any ſtar near the northern part of the horizon, and if you travel to the ſouth, it will ſeem to dip farther and farther downwards, till by proceeding on, it will deſcend entirely out of ſight. In the mean time, the ſtars to the ſouthward of our traveller will ſeem to riſe higher and higher. The contrary appearances would happen, if he went to the northward. This proves that the earth is not a plane ſurface, but a curve in the direction ſouth and north. By an obſervation nearly ſimilar to this, the traveller may prove the curvature of the earth, in an eaſt and weſt direction.

The globular figure of the earth may be alſo inferred from the operation of *levelling*, or the art of conveying water from one place to another: for in this proceſs, it is found neceſſary to make an allowance between the true and apparent level; or in other words, for the figure of the earth. For the

the *true level* is not a *ſtrait* line, but a *curve* which falls below the ſtrait line about eight inches in a mile, four times eight in two miles, nine times eight in three miles, ſixteen times eight in four miles, always increaſing as the ſquare of the diſtance.

What the earth loſes of it's ſphericity by mountains and vallies, is very inconſiderable; the higheſt eminence bearing ſo little proportion to it's bulk, as to be ſcarcely equivalent to the minuteſt protuberance on the ſurface of a lemon.

It is proper, however, to acquaint you, that though we call our earth a globe, and that when ſpeaking in general terms, it may be conſidered as ſuch; yet in the ſtrictneſs of truth, it muſt be obſerved, that it is not exactly and perfectly a ſphere, but is a *ſpheroid, flattened a little towards the poles, and ſwelling at the equator;* the equatorial diameter being about thirty-four miles longer than the diameter from pole to pole.

Of the Diurnal Motion of the Earth.

Though it is this motion which gives us the grateful viciſſitude of day and night, adjuſted to the times of labour and reſt; yet moſt people find ſome difficulty in conceiving that the earth moves; the more ſo, becauſe, in order to allow it, they muſt give up, in a great meaſure, the evidence of their exterior ſenſes, of which the impreſſions are exceeding ſtrong and lively. It will, therefore, be neceſſary to prove to you, that you can by no means infer that the earth is at reſt, becauſe it appears to be ſo, and to convince you by a variety of *facts*, that reaſon was given to correct the *fallacies* of the *ſenſes*.

To this end we ſhall here point out ſome in-

ſtances, where apparent motion is produced in a body at reſt, by the real motion of the ſpectator. Let us ſuppoſe a man in a ſhip to be carried along by a briſk gale, in a direction parallel to a ſhore, at no great diſtance from him; while he keeps his eye on the deck, the maſt, the ſails, or any thing about the ſhip; that is to ſay, while he ſees nothing but ſome part of the veſſel on board of which he is, and conſequently every part of which moves with him, he will not perceive that the ſhip moves at all. Let him, after this, look to the ſhore, and he will ſee the houſes, trees, and hills, run from him in a direction contrary to the motion of the veſſel; and ſuppoſing him to have received no previous information on this ſubject, he might naturally conclude, that the apparent motion of theſe bodies was real.

In a ſimilar ſituation to this, we may conceive the inhabitants of the earth; who, in early times, knowing nothing of the true ſtructure or laws of the univerſe, ſaw the ſun, the ſtars, and the planets, riſe and ſet, and perform an apparent revolution about the earth. They had no idea of the motion of the earth, and therefore all this appearance ſeemed reality. But as it is highly reaſonable to ſuppoſe, that as ſoon as the ſlighteſt hint ſhould be given to the man, of the motion of the veſſel, he would begin to form a new opinion, and conceive it to be more rational, that ſo ſmall a thing as the ſhip ſhould move, rather than all that part of the earth which was open to his view; ſo, in the ſame manner, no ſooner was an idea formed of the vaſt extent and greatneſs of the univerſe, with reſpect to this earth, than mankind began to conceive it would be more rational that the earth ſhould move, than the whole fabric of the heavens.

By another familiar inſtance, it will be eaſy to ſhew you, that as the eye does not perceive it's own

own motion, it always judges from appearances. Go into a common windmill, and desire the miller to turn the mill round, while you are sitting within it with your eyes fixed on the upright post in the center thereof; this post, *though at rest*, will appear to you *to turn round* with considerable velocity, the real motion of the mill being the cause of the apparent motion of the swivel post.

Sea-faring people are furnished with various instances to illustrate this subject; those who are busy in the hold of a ship at anchor, cannot by any perception determine whether the ship has swung round or not by the turn of the tide. When a ship first gets under way with a light breeze, she may be going at a good rate before those who are between decks can perceive it. Having thus obviated the objections which arise from the testimony of the senses, we may now proceed to consider the arguments which tend more directly to prove the motion of the earth.

All the celestial motions will, on this supposition, be incomparably more simple and moderate.

This opinion is much more agreeable to our notions of final causes, and our knowledge of the œconomy of nature; for if the earth be at rest, and the stars, &c. move round it once in 24 hours, their velocity must be immense; and it is certainly more agreeable to reason, that one single body, and that one of the smallest, should revolve on it's own axis in 24 hours, than that the whole universe should be carried round it, in the same time, with inconceivable velocity.

The rotation of the earth round it's axis is analogous to what is observed in the sun, and most of the planets; it being highly probable, that the earth, which is itself one of the planets, should

have the ſame motion as they have, for producing the ſame effect: and it would be as abſurd in us to contend for the motion of the whole heavens round us in 24 hours, rather than allow a diurnal motion to our globe, as it would be for the inhabitants of Jupiter to inſiſt that our globe, and the whole heavens, muſt revolve round them in ten hours, that all it's parts might ſucceſſively enjoy the light, rather than grant a diurnal motion to their habitation.

All the phenomena relative to this ſubject are as eaſily ſolved on the ſuppoſition of the earth's diurnal motion, as on the contrary hypotheſis.

Beſides the foregoing conſiderations, there are ſeveral arguments to be deduced from the higher parts of aſtronomy, which *demonſtrably* prove the diurnal motion of the earth.

OF THE PHENOMENA OCCASIONED BY THE EARTH'S DIURNAL ROTATION.

As the earth is of a ſpherical figure, that part which at any time comes under the confined view of an obſerver, will ſeem to be extended like a plane; and the heavens will appear as a concave ſpherical ſuperficies divided by the aforeſaid plane in two parts, one of which is concealed from us by the opacity of the earth.

Now the earth, by it's revolution round it's axis, *carries the ſpectator and the aforeſaid plane from weſt to eaſt*; therefore all thoſe bodies which could not be ſeen becauſe they were below the plane of the horizon, will become viſible, or riſe above it, when, by the rotation of the earth, the horizon ſinks as it were below them. On the other hand, the oppoſite part of the plane, towards the weſt,

weſt, riſing above the ſtars on that ſide, will hide them from the ſpectator, and they will appear to ſet, or go below the horizon.

As the earth, together with the horizon of a ſpectator, continues moving to the eaſt, and about the ſame axis, all ſuch bodies as are ſeparated from the earth, and which do not partake of that motion, will ſeem to move uniformly in the ſame time, but in an oppoſite direction, that is, from EAST TO WEST; excepting the celeſtial poles, which will appear to be at reſt. Therefore, when we ſay, that the whole concave ſphere of the heavens appears to turn round upon the axis of the world, whilſt the earth is performing one rotation round it's own axis, we muſt be underſtood to except the two poles of the world, for theſe do not partake of this apparent motion.

It is, therefore, on account of the revolution of the earth round it's axis, that a ſpectator imagines the whole ſtarry firmament, and every point of the heaven, (excepting the two celeſtial poles) to revolve about the earth from eaſt to weſt every twenty-four hours, each point deſcribing a greater or leſs circle, as it is more or leſs remote from one of the celeſtial poles.

Although every place on the ſurface of the terraqueous globe is illuminated by all the ſtars which are above the horizon of that place; yet when the *ſun* is above the horizon, his light is ſo ſtrong, that it quite extinguiſhes the faint light of the ſtars, and produces *day*. When the *ſun* goes below the horizon, or more properly, when our horizon gets above the ſun, the ſtars give their light, and we are in that ſtate which is called NIGHT.

Now as the earth is an opake ſpherical body, at

at a great diſtance from the ſun, ONE HALF of it will always be illuminated thereby, while the other half will remain in darkneſs.

The circle which diſtinguiſhes the illuminated face of the earth from the dark ſide, and is the boundary between light and darkneſs, is generally called the TERMINATOR. A line drawn from the center of the ſun to the center of the earth, is perpendicular to the plane of this circle.

When any point in the globe firſt gets into the enlightened hemiſphere, the ſun is juſt riſen to that part; when it gets half-way, or to it's greateſt diſtance from the terminator, it is then NOON; and when it leaves the enlightened hemiſphere, it is then SUN-SET; but it ſtill enjoys ſome light from the ſun, which is reflected by the atmoſphere, till it gets eighteen degrees beyond the terminator; this glimmering light is called TWILIGHT.

OF THE CORRESPONDENCE OF THE CELESTIAL AND TERRESTRIAL CIRCLE.

As the earth daily revolves on it's axis, every point on it's ſurface is ſucceſſively preſented to all the points in the heavens, deſcribing circles whoſe planes are perpendicular to it's axis, and their centers therein; whence it follows, that thoſe planes are parallel to each other, and may be conſidered as the elements of a ſphere.

Therefore all the ſtars muſt ſeem to turn every day uniformly about the earth's axis, and in parallel circles, as though they were placed in the concavity of a ſphere to which the earth is concentric.

The two points at the extremities of the earth's axis whereon it turns, are the only points of it's ſurface

ſurface that do not change their places; every other point deſcribes a circle greater as it is farther diſtant from thoſe fixed points or *poles*.

In the heavens, therefore, there muſt be two points, P Q, *fig*. 3, *pl*. 2, that appear fixed, wherein a ſtar can have no apparent motion; theſe points are determined in the heavens, by prolonging the axis of the earth; theſe are the poles of a great circle of the celeſtial ſphere, formed in the heavens by continuing the plane of the terreſtrial equator, and all the ſtars will appear to turn round theſe two poles.

Thus the axis p q, of the earth p e q z, *fig*. 3, *pl*. 2, are the poles of a great circle E T Z of the celeſtial ſphere, formed in the heavens by continuing the plane of the terreſtrial equator e z z, and all the ſtars will appear to turn round the two poles P, Q, or rather round the axis P Q. Let P repreſent the north pole, Q the ſouth pole.

If through the center of the earth C, and any point m on it's ſurface, a right line C m be ſuppoſed prolonged to the heavens, the extremity M of that right line will, by the earth's diurnal rotation, deſcribe the celeſtial parallel L M M L, anſwering to the terreſtrial parallel l m m l of the point m. And if C M be ſuppoſed to be prolonged on the other ſide to the heavens in T, then T will deſcribe in the heavens a parallel T T V V equal to the parallel L M M L, anſwering to, and having the ſame declination with the terreſtrial parallel t t u u.

Hence it follows, 1. That the plane of the celeſtial parallel L M M L, and that of the correſpondent parallel l m m l, are ſimilar elements of a cone, whoſe axis is the ſame as that of the earth, and whoſe vertex C is at the earth's center. *Therefore the plane of a celeſtial parallel cannot be the ſame*

ſame with it's correſponding terreſtrial parallel' only the plane (E Z Z) of the celeſtial equator is the ſame with the plane e z z of the terreſtrial equator.

2. When in the earth's diurnal rotation a ſtar paſſes through the obſerver's zenith, the parallel of that ſtar correſponds with the obſerver's terreſtrial parallel; that is to ſay, the celeſtial parallel is as far diſtant from the celeſtial equator, as the terreſtrial parallel is from the terreſtrial equator: for then the line of the obſerver's zenith is a right line drawn from the earth's center through the obſerver's eye, terminating at the ſtar, and is the line that deſcribes the ſtar's parallel in the heavens.

If therefore the arc M Z, the diſtance of the ſtar M from the celeſtial equator be meaſured, it gives alſo the meaſure of the arc m z, the obſerver's diſtance from the terreſtrial equator. *Therefore the arc of the obſerver's diſtance from the terreſtrial equator, is equal to the declination of the ſtar that paſſes through his zenith.* So that if it be a fixed ſtar, and the obſerver changes his place, the different declinations of the ſtars that paſs through his zenith at the various places he comes to, will ſhew how much he approaches to, or recedes from the equator.

It follows, laſtly, *that any place on the terreſtrial ſphere may be repreſented by it's correſponding zenith point in the heavens.* For the celeſtial parallel paſſing through that point, repreſents the terreſtrial parallel of the place, and the declination of the celeſtial parallel meaſuring the diſtance of that place from the equator; alſo the great circle of the celeſtial ſphere deſcribed from that zenith as a pole, denotes the plane of the horizon of that place, and the particular phenomena of a place on the earth may be explained, by denoting that place

no

no otherwiſe than by it's zenith in the heavens. *

OF THE ANNUAL MOTION OF THE EARTH.

It is owing to the induſtry of modern aſtronomers, that the annual motion of the earth has been fully evinced; for though this motion had been known to, and adopted by many among the ancient philoſophers, yet they were not able to give their opinions that degree of probability, which is attainable from modern diſcoveries, much leſs the evidence ariſing from thoſe demonſtrative proofs, of which we are now in poſſeſſion. I ſhall, therefore, enumerate ſome of the reaſons which induce aſtronomers to believe *that the earth moves round the ſun*, and then explain further the nature of this motion, which is calculated to afford us the uſeful and delightful variety of the ſeaſons, the mutual allay of immoderate heat and cold, and the ſucceſſive growth and recruit of vegetation.

On the ſuppoſition of the earth's motion, the celeſtial motions become incomparably more ſimple, and free from thoſe looped contortions which muſt be ſuppoſed in the other caſe, and which are not only extremely improbable, but incompatible with what we know of motion.

This opinion is alſo more reaſonable, on account of the extreme *minuteneſs* of the earth, when compared with the *immenſe* bulk of the ſun, Jupiter, and Saturn; and there are no known laws of motion, according to which ſo great a body as the ſun can revolve about ſo ſmall a one as the earth.

The *ſun* is the *fountain* of light and heat, which

* The whole of what is ſaid under this head, may be beautifully illuſtrated by the armillary ſphere.

which it darts through the whole ſyſtem; it ought, therefore, to be in the *center*, that it's influence may be regularly diffuſed through the whole heavens, and communicated in juſt gradations to the whole ſyſtem.

When we conſider the *ſun* as the center of the ſyſtem, we find all the bodies moving round it, agreeable to the univerſal laws of gravity; but upon any other conſideration we are left in the dark.

The motion of the earth round the ſun accords with that general harmony, and univerſal law, which all the other moving bodies in the ſyſtem obſerve, namely, *that the ſquares of the periodic times are as the cubes of the diſtances*; but if the ſun moves round the earth, that law is deſtroyed, and the general order of ſymmetry in nature interrupted.

The annual motion of the earth is *inconteſtibly proved* by obſervation, a motion having been diſcovered in all the fixed ſtars, which ariſes from a combination of the motion of light with the motion of the earth in it's orbit.

It will be clearly ſhewn in it's place, that Venus and Mercury *move round* the ſun in orbits that are *between* it and the earth; that the orbit of the earth is ſituated *between* that of Venus and Mars; and that the orbits of Mars, Jupiter, &c. are *exterior* to, and *include* the other three.

OF THE APPARENT MOTION OF THE SUN, ARISING FROM THE EARTH'S ANNUAL MOTION ROUND IT.

As when a perſon ſails along the ſea coaſt, the ſhore, the villages, and other remarkable places on land, appear to change their ſituation, and to paſs by him; ſo it is in the heavens. To a ſpectator upon the earth, as it moves along it's orbit, or ſails as it were through celeſtial ſpace, the ſun, the planets,

nets, and the fixed ſtars, appear to change their places.

Apparent change of place is of two ſorts; the one is that of bodies at reſt, the change of whoſe place depends ſolely on that of the ſpectator; the other is that of bodies in motion, whoſe apparent change of place depends as well on their own motion, as on that of the ſpectator.

I ſhall firſt conſider only that apparent change which takes place in thoſe which are at reſt, and which is owing wholly to the motion of the earth; and ſhew that the ſun, when ſeen from the earth, will appear to move in the ſame manner, whether it revolves round the earth, or whether the earth revolves round the ſun.

Let us ſuppoſe the earth at reſt, without any motion of it's own, and let the ſun be ſuppoſed to revolve round it in the orbit A B C D, *fig.* 1, *pl.* 4, and let E F G H be a circle in the concave ſphere of the ſtarry heavens; as the ſun moves in the order of the letters A B C D in it's orbit, it will appear to a ſpectator on the earth to have deſcribed the circle E F G H. When the ſun is at A, it will appear as if it was among the fixed ſtars that are at E; when it is at B, it will appear among the fixed ſtars at F; when at G, among thoſe at H; and when it is at D, it will appear among the fixed ſtars at G. Indeed, the fixed ſtars and the ſun are not ſeen at the ſame time; but I have ſhewn, that we may tell in what part of the heavens the ſun is, or what fixed ſtars it is near, by knowing thoſe which are oppoſite to it, or come to the ſouth at midnight. Therefore, if we find that any ſet of ſtars, as thoſe at G for inſtance, come to the ſouth at midnight, we may be ſure that they are oppoſite to the ſun; and conſequently, if we could ſee the ſtars in that part of the heaven where the ſun is, we ſhould find them to be thoſe at F.

Secondly,

Secondly, let us ſuppoſe that S is the ſun, that it has no motion of it's own, that it reſts within the orbit A B C D, in which we ſhall now ſuppoſe the earth to move, in the order of the letters A B C D. Upon this ſuppoſition, when the earth is at A, the ſun will appear in that part of the heavens where the ſtars H are; when the earth is at B, the ſun will appear in that part of the heavens where the ſtars G are; when the earth is at C, the ſun will appear in that part of the heavens where the ſtars E are; and as the earth revolves round the ſun, in the orbit A B C D, the ſun will appear to a ſpectator on the earth to deſcribe the circle G H E F.

Thus whether the *earth be at reſt*, and the ſun revolves in the orbit A B C D; or the *ſun be at reſt*, and the earth revolves in the ſame orbit, a ſpectator on the earth will ſee the ſun deſcribe the ſame circle E F G H, in the concave ſphere of the heavens.*

Hence if the plane of the earth's orbit be imagined to be extended to the heavens, it would cut the ſtarry firmament in that very circle, in which a ſpectator in the ſun would ſee the earth revolve every year: while an inhabitant of the earth would obſerve the ſun to go through the ſame circle, and in the ſame ſpace of time that the ſolar ſpectator would ſee the earth deſcribe it.

The inhabitants of all the other planets will obſerve juſt ſuch motions in the ſun as we do, and for the very ſame reaſons; and the ſun will be ſeen from every planet to deſcribe the ſame circle, and in the ſame ſpace of time, that a ſpectator in the ſun would obſerve the planet to do. For example, an inhabitant of Jupiter would think that the ſun revolved

* This is pleaſingly illuſtrated by the armillary ſphere, where the ſphere may be moved independent of the earth, and the earth of the ſphere.

revolved round him, describing a circle in the heavens in the space of twelve years: this circle would not be the same with our ecliptic, nor would the sun appear to pass through the same stars which he does to us. On the same account, the sun, seen from Saturn, will appear to move in another circle, distinct from either of the former; and will not seem to finish his period in less time than thirty years. Now as it is impossible that the sun can have all these motions really in itself, we may safely affirm, that none of them are real, but that they are all apparent, and arise from the motions of the respective planets.

One phenomenon arising from the annual motion of the earth, which has already been slightly touched upon, may now be more fully explained; for as from this motion, the sun appears to move from west to east in the heavens, if a star rises or sets along with the sun at any time, it will in the course of a few days rise or set before it, because the sun's apparent place in the heavens will be removed to the eastward of that star. Hence those stars which at one time of the year set with the sun, and therefore do not appear at all, shall at another time of the year rise when the sun sets, and shine all the night. And as any one star shifts it's place with respect to the sun, and in consequence of that with respect to the hour of the night, so do all the rest. Hence it is that all those stars, which at one time of the year appear on any one side of the pole star in the evening, shall in half a year appear on the contrary side thereof.

From what has been said it follows in general, 1. *That, in whatever regards the sun's place, only with respect to the point in the heavens in which it appears, it may be supposed to move in an infinitely great circle, called the ecliptic, whose center is the observer's eye.*

2. That *the earth's true place in his orbit being known,* from obſervation or calculation; *ſix ſigns added to or ſubtracted from it, gives the ſun's true place in the ecliptic.* Therefore the theory of the ſun's motions ſeen from the earth, is the ſame with that of the earth's motions ſeen from the ſun.

3. *To an inhabitant on the earth, the plane of the ecliptic is that, whereto the annual motions of the planets in their orbits muſt be naturally compared.* In the ſame manner, as the plane of the equator is that whereto the poſition of the parallels, which the ſtars appear to deſcribe in conſequence of the earth's diurnal revolution, muſt alſo be compared.

In order to combine the ſun's annual motion with it's diurnal, you are to obſerve, that if *the plane of the ecliptic* coincided with that of the *equator,* the ſun would, by it's diurnal revolution, ſeem to deſcribe every day the ſame circle, viz. the equator; and could therefore have no declination. For in deſcribing the ecliptic by it's annual revolution, the ſun would then ſucceſſively anſwer to all the ſtars in the equator, conſequently, it's diurnal revolution would be made in the ſame circle as that of the ſtars; but I have already obſerved to you, that the ſun appears to deſcribe daily different parallels; it is evident, therefore, that the plane of the ecliptic does not coincide with that of the equator, but is inclined thereto.

If ſo, the ſun muſt, in conſequence of it's annual motion, deſcribe a great circle N B T L N, *fig.* 4, *pl.* 2, repreſenting the ecliptic, and biſecting the equator E B Z L E. The ſun muſt therefore appear ſometimes towards one pole, ſometimes towards the other pole.

1. Let us ſuppoſe that it is in B, one of the interſections of the equator and the ecliptic, it's diurnal revolution muſt deſcribe the equator, and have no declination; as the ſun gradually advances

in

n the ecliptic from B towards A, it appears gradually to recede from the equator with an increasing northern declination, and to describe smaller and smaller parallels, till it arrives at A, where it appears to describe the parallel A I V A.

2. The sun being arrived at L, three signs or 90 degrees from B, and three months after his departure therefrom, it is then in that point of the ecliptic the most distant from the equator at it's greatest northern declination, and describes the smallest parallel O T.

3. In the three following months the sun going from T to L draws nearer the equator, it's northern declination diminishes, it's parallels augment; so that when arrived in L, the other intersection of the equator and the ecliptic, it then has no declination, and that day again describes the celestial equator.

4. The sun after that passing from L to N, enters the south part of the heavens, it's southern declination then increases, and it's parallels diminish, till being come to N, three signs from the point L, it's southern declination is then the greatest, and it describes it's least parallel N D.

5. The sun continuing it's course from N to B again draws nearer the equator, and it's southern declination diminishes; so that when returned to B a year after it's departure from that point, it is again in the equator and without declination, and then begins a new course attended with the same phenomena.

It is evident, therefore, *that the sun moving continually in the ecliptic, the parallels it every day describes cannot be circles, but a kind of spirals*, such as the curves made by a thread wound about a sphere. For after a diurnal revolution, the sun does not come to the same point from whence it departed, but according as it approached to, or re-

ceded from the equator, is either a little below or above that point.

The angle formed by the plane of the equator and ecliptic, is called the *obliquity of the ecliptic.*

The obliquity of the ecliptic is equal to the ſun's greateſt declination, namely, when in the tropic, and is about 23 ½ degrees; conſequently, the axis of the earth muſt be inclined to the ecliptic in an angle of 66 ½ degrees. The conſideration of this obliquity brings us to an explanation.

Of the Seasons of the Year.

It is our buſineſs under the preſent head to account for the *phenomena of the ſeaſons*, thoſe grateful viciſſitudes on which ſo much both of the buſineſs and happineſs of man depends.

Before I explain the cauſes of thoſe changes that are termed the *ſeaſons of the year*, it will be neceſſary to premiſe a few conſiderations: Firſt, that on account of the immenſe diſtance of the ſun from the earth, the rays which proceed from it may be conſidered as parallel to each other. Secondly, that only one-half of a globe can be illuminated by parallel rays, and therefore only one-half of the earth will be enlightened by the ſun at one time. Thirdly, that we may call the line which divides light from darkneſs, the terminator.

In the diagram, *fig.* 1, *pl.* 5, S repreſents the ſun, from which we ſuppoſe parallel rays to flow in all directions; A, B, C, repreſent three different poſitions of the globe of the earth, the bright part being that which is illuminated by the rays proceeding from the ſun; the dark part, the portion of the globe which is in obſcurity at theſe dif-

different ſituations ; N the north, S the ſouth pole of the globe, T T the terminator or boundary of light and darkneſs.

At C, the poles coincide with the terminator.

At A, the north pole is altogether in the *illuminated* hemiſphere, and the ſouth pole in the *dark* hemiſphere.

At B, the ſouthern pole is in the *enlightened* part, and the north pole in the *dark* hemiſphere.

It is evident that it is day in any given place on the globe, ſo long as that place continues in the enlightened hemiſphere ; but when, by the diurnal rotation of the earth on it's axis, it is carried into the dark hemiſphere, it becomes night to that place.

The length of the day and the night depend on the poſition of the terminator, with reſpect to the axis of the earth.

If the poles of the earth be ſituated in the terminator, as at C, every parallel will be divided into two equal parts ; and as the uniform motion of the earth cauſes any given place to deſcribe equal parts of it's parallel in equal times, the day and the night would be equal on every parallel of latitude, that is, all over the globe, except at the poles, where the ſun would neither riſe nor ſet, but continue in the horizon.

But if, as at A and B, the axis be not placed in the plane of the terminator, the terminator will divide the equator into two equal parts, but all the circles parallel to it into unequal parts ; thoſe circles that are ſituated towards the enlightened pole, will have a greater part of their circumference in the enlightened than in the dark hemiſphere ; while ſimilar parallels toward the other pole will have the greater part of their circumference in the dark hemiſphere. Whence it follows, that the firſt-

mentioned parallels will enjoy longer days than nights; and the contrary will happen to the latter, where the days will be the ſhorteſt, and the nights the longeſt; while at the equator, the days and nights continue equal. All this is evident from the bare inſpection of the figures; it is alſo obſervable, that the diſproportion is greateſt in the greateſt latitude; and that thoſe places, whoſe diſtance from the pole is leſs than that of the pole from the terminator, muſt enjoy either a conſtant day, or a conſtant night; becauſe they are never carried into the oppoſite hemiſphere by the diurnal rotation of the earth. In this poſition of the axis, the inhabitants on one ſide of the equator may be ſaid to enjoy ſummer, and thoſe on the other ſide winter, with reſpect to each other.

From what has been ſaid, it is plain that the viciſſitudes in the days and nights are occaſioned by the poſition of the terminator, or boundary of light and darkneſs, with the axis of the earth; or in other words, by the different aſpect of the earth with reſpect to the ſun.

We have now only to ſhew what cauſes the changes of poſition in the terminator, which are, 1. The *inclination* of the earth's axis to the plane of the ecliptic, or orbit in which it moves. 2. That through the whole of it's annual courſe, the axis of the earth preſerves it's poſition, or continues *parallel to itſelf*; that is, if a line be conceived as drawn parallel to the axis while the earth is in any one point of it's orbit, the axis will in every other poſition of the earth be parallel to the ſaid line.

If the axis of the earth were *perpendicular* to the plane of it's orbit, the equator and the orbit (or ecliptic) would coincide; and as the ſun is always in the plane of the ecliptic, it would in this caſe

caſe be always over the equator, and the two poles would be in the terminator, and there would be no diverſity in the days and nights, and but one ſeaſon of the year; but as this is not the caſe, we may fairly infer, that the axis of the earth is not perpendicular to the plane of it's orbit.

But if the earth's axis be *inclined to the plane of the ecliptic* when the earth is in the ſituation repreſented at A, *pl.* 5, the pole N will be towards the ſun, and the pole S will be turned from it; but juſt the contrary will happen, when the earth, by going half round the ſun, has arrived at the oppoſite point in it's orbit. Hence the ſun will not be always in the equator, but at one time of the year it will appear nearer to one of the poles, and at the oppoſite ſeaſon, it will appear nearer to the other. To this circumſtance the change of ſeaſons is owing; for when the ſun leaves the equator and approaches to one of the poles, it will be ſummer on that ſide of the equator, and when the ſun departs from thence and approaches to the other pole, it will be winter. Thus from the inclination of the axis, each part of the earth enjoys the benefit of ſummer in it's turn; for it is evident, from what has been ſaid already, that when it is winter towards one of the poles, on one ſide the equator, it is ſummer towards the other pole, or on the other ſide of the equator.

A better notion of the effect of the inclination of the earth's axis will be obtained by obſerving *fig.* 2, *pl.* 5, in which the ellipſis repreſents the earth's orbit, ſeen at a diſtance; the eye ſuppoſed to be elevated a little above the plane of it. The earth is here repreſented in the firſt point of each of the twelve ſigns, as marked in the figure, with the twelve months annexed; e the pole, and

e d the axis of the ecliptic, always perpendicular to the plane of the orbit; P the north pole of the world; P m it's axis, about which the earth's daily motion is made from weſt to eaſt. P C E ſhews the angle of it's inclination, which preſerves it's paralleliſm through every part of it's orbit.

When the earth is in the firſt point of Libra, the ſun then appears in the oppoſite point of the ecliptic at Aries, about the twenty-ſecond of September, N. S. and when the earth is in Aries, the ſun will then appear in Libra about the 19th of March; at which times of the year the edge of the enlightened hemiſphere is parallel to the ſolſtitial colure, *fig.* 8, and paſſes through the two poles of the world, dividing every parallel to the equator into two equal parts; whence the diurnal parallel of every inhabitant on the ſurface of the earth will, at either of theſe ſeaſons, be half in the illuminated, and half in the obſcure part of the earth; conſequently the day and night will be equal in all places.

Conceive the earth to have moved from ♎ Libra to ♑ Capricorn, it's line of direction keeping it's paralleliſm will now coincide with the ſolſtitial colure, *fig.* 8, and the edge of the diſc will be perpendicular thereto, and paſs through e the pole of the ecliptic. In this ſituation of the earth, all places within the northern polar circle are illuminated throughout the whole diurnal revolution, at which time their inhabitants ſee the ſun longer than 24 hours; but thoſe which lie under the polar circle touch the edge of the diſc, and therefore their inhabitants only ſee the ſun ſkim quite round their horizon at it's firſt appearance. Every other parallel interſects the edge of the diſc, and as the illuminated part of each is much greater than the obſcure part, the days are conſequently at this

ſeaſon

ſeaſon of the ſummer ſolſtice, which happens about the 21ſt of June, longer than the nights. While the earth is moving from Libra through Capricorn to Aries, the north pole P being in the illuminated hemiſphere, will have ſix months continual day; but while the earth paſſes from Aries through Cancer to Libra, the north pole will be in the obſcure part, and have continual nights, the ſouth pole of the globe at the ſame time enjoying continual day. When the earth is at Cancer, the ſun appears at Capricorn. At this ſeaſon the nights will as much exceed the days, as the days exceeded the nights when the earth was in the oppoſite point of her orbit; for the nocturnal arches, or obſcure part of their paths, are here equal to the illuminated parts when the earth was at Capricorn; and the illuminated part is here no more than the obſcure part was in that place.

By conſidering the three globes, A B C, *fig.* 1, *pl.* 5, you may gain a clear idea of the daily apparent change in the ſun's declination; there is a line drawn from the center of the ſun to the center of each globe; it is broader than the other lines. This line may be called the *central ſolar ray.* About the 21ſt of December, when the earth is in Cancer, this ray will terminate or fall upon the ſouthern tropic, as at D; or the tropic of Capricorn, as at B; and conſequently, by the earth's rotation round her axis, the inhabitants of every part of this circle will ſucceſſively have the ſun in their zenith; or in other words, he will be vertical to them that day at noon, as the ſun appears that day to be carried round in the tropic of Capricorn.

About the 20th of March, the earth is at Libra, and the ſun will then appear in Aries; the central ſolar ray terminates upon the ſurface of the earth, in the equator, as at C; and therefore the ſun

ſun, appears to be carried round in the celeſtial equator, and is ſucceſſively vertical to thoſe who live under that circle.

About the 21ſt of June, when the earth is in Capricorn, the central ſolar ray terminates on the ſurface of the earth, in the northern tropic, as at A; and for that day the ſun appears to be carried round in the tropic of Cancer, and is vertical to thoſe who live under that circle. About the 22d of September, the earth is in Aries, and the ſun in Libra, and the central ſolar ray again terminates at the equator; conſequently the ſun again appears in the celeſtial equator, and is vertical to thoſe who live under it.

We have ſeen, that as the ſun moves in the ecliptic, from the vernal equinox to the tropic of Cancer, it gets to the north of the equator, or it's declination towards our pole increaſes. Therefore, from the vernal equinox, when the days and nights are equal, till the ſun comes to the tropic of Cancer, our days lengthen, and our nights ſhorten; but when the ſun comes to the tropic of Cancer, it is then in it's utmoſt northern limit, and returns in the ecliptic to the equator again. During this return of the ſun, it's declination towards our pole decreaſes, and conſequently the days decreaſe, and the nights increaſe, till the ſun is arrived in the equator again, and is in the autumnal equinoctial point, when the days and nights will again be equal. As the ſun moves from thence towards the tropic of Capricorn, it gets to the ſouth of the equator; or it's declination towards the ſouth pole increaſes. Therefore, at that time of year, our days ſhorten, and our nights lengthen, till the ſun arrives at the tropic of Capricorn; but when the ſun is arrived there, it is then at it's utmoſt ſouthern limit, and returns in the ecliptic to the

the equator again. During this return, it's diſtance from our pole leſſens, and conſequently the days will lengthen, as the nights will ſhorten, till they become equal, when the ſun is come round to the vernal equinoctial point.

Our ſummer is nearly eight days longer than the winter.

By ſummer is meant here the time that paſſes between the vernal and autumnal equinoxes; by winter, the time between the autumnal and vernal equinox. The ecliptic is divided into ſix northern, and ſix ſouthern ſigns, and interſects the equator at the firſt of Aries, and the firſt of Libra. In our ſummer, the ſun's apparent motion is through the ſix northern, and our winter through the ſix ſouthern ſigns; yet the ſun is 186 days, 11 hours, 51 minutes, in paſſing through the ſix firſt; and only 178 days, 17 hours, 58 minutes, in paſſing through the ſix laſt. Their difference, 7 days, 17 hours, 53 minutes, is the length of time by which our ſummer exceeds the winter.

In *fig.* 1, *pl.* 6, A B C D repreſents the earth's orbit; S the ſun in one of it's foci; when the earth is at B, the ſun appears at H, in the firſt point of Aries; and whilſt the earth moves from B through C to D, the ſun appears to run through the ſix northern ſigns, from ♈ through ♋ to ♎ at F. When the earth is at D, the ſun appears at F, in the firſt point of Libra; and as the earth moves from D through A to B, the ſun appears to move through the ſix ſouthern ſigns, from ♎ through ♑ to Aries at H.

Hence the line F H, drawn from the firſt point of Aries through the ſun at S, to the firſt point of ♎, divides the ecliptic into two equal parts; but the ſame line divides the earth's elliptical orbit into two unequal parts. The greater part

part B C D is that which the earth defcribes in the fummer, while the fun appears in the northern figns. The leffer part is D A B, which the earth defcribes in winter, while the fun appears in the fouthern figns. C the earth's aphelion, where it moves floweft, is in the greater part; A it's perihelion, is in the leffer part, where the fun moves fafteft.

There are, therefore, two reafons why our fummer is longer than our winter; firft, becaufe the fun continues in the northern figns, while the earth is defcribing the greater part of it's orbit; and fecondly, becaufe the fun's apparent motion is flower while it appears in the northern figns, than whilft it appears in the fouthern ones.

The fun's apparent diameter is greater in our winter than in fummer, becaufe the earth is nearer to the fun when at A in the winter, than it is when at C in the fummer. The fun's apparent diameter, in winter, is 32 minutes, 47 feconds; in fummer, 31 minutes, 40 feconds.

But if the earth is farther from the fun in fummer than in winter, it may be afked, why our winters are fo much colder than our fummers. To this it may be anfwered, that our fummer is hotter than the winter, firft, on account of the greater height to which the fun rifes above our horizon in the fummer; fecondly, the greater length of the days. The fun is much higher at noon in fummer than in winter, and confequently, as it's rays in fummer are lefs oblique than in winter, more of them will fall upon the furface of the earth. In the fummer, the days are very long, and the nights very fhort; therefore the earth and air are heated by the fun in the day-time, more than they are cooled in the night;

 and

and upon this account, the heat will keep increaſing in the ſummer, and for the ſame reaſon will decreaſe in winter, when the nights lengthen.

I ſhould exceed the limits of a Lecture, if I were to inquire into the ſeveral concurring cauſes of the temperatures that obtain in various climates; it may be ſufficient, therefore, to obſerve what a remarkable proviſion is made in the world, and the ſeveral parts of it, to keep up a perpetual change in the degrees of heat and cold. Theſe two are antagoniſts, or as Lord Bacon calls them, *the very hands of nature with which ſhe chiefly worketh*, the one expanding, the other contracting bodies, ſo as to maintain an oſcillatory motion in all their parts; and ſo ſerviceable are theſe changes in the natural world, that they are promoted every year, every hour, every moment. From the oblique poſition of the ecliptic, the earth continually preſents a different face to the ſun, and never receives his rays two days together in the ſame direction. In the day and night, the differences are ſo obvious, that they need not to be mentioned, though they are moſt remarkable in thoſe climates, where the ſun at his ſetting makes the greateſt angle with the horizon. Every hour of the day, the heat varies with the ſun's altitude, is altered by the interpoſition of clouds, and the action of winds; and there is little room to doubt, but what the various changes that thus take place, concur in producing many of the ſmaller and greater phenomena of nature.

Be this however as it may, it is certain that the various irregularities and intemperature of the elements, which ſeem to deſtroy nature in one ſeaſon, ſerve to revive it in another: the immoderate heats of ſummer, and the exceſſive cold of winter, prepare

prepare the beauties of the ſpring, and the rich fruits of autumn. Theſe viciſſitudes, which ſeem to ſuperficial minds the effects of a fortuitous concourſe of irregular cauſes, are regulated according to weight and meaſure by that SOVEREIGN WISDOM, who weighs the earth as a grain of ſand, the ſea as a drop of water.

Our obſervations on the ſeaſons cannot be better concluded than in the words of the excellent *Hooker*. A long and uninterrupted enjoyment of bleſſings is apt to extinguiſh in us that gratitude towards the author of them, which it ought to cheriſh and invigorate; the courſe of nature often glides on unobſerved when there are no variations therein; and the ſun himſelf ſhineth unnoticed, becauſe he ſhineth every day. Since the time that GOD did firſt proclaim the edicts of his law, ſays *Hooker*, heaven and earth have hearkened unto his voice, and their labour has been to do his will. But if nature ſhould intermit her courſe, and leave altogether, though it were but for a while, the obſervation of her laws; if thoſe principles and mother elements, whereof all things in this world are made, ſhould loſe the qualities they now poſſeſs; if the frame of that heavenly arch erected over our heads ſhould looſen and diſſolve itſelf; if the celeſtial globes ſhould forget their wonted motions, and by irregular volubility turn themſelves any way as it might happen; if the prince of the lights of heaven, which now as a giant doth run his unwearied courſe, ſhould as it were through a languiſhing faintneſs begin to ſtand and to reſt himſelf; if the moon ſhould wander from her beaten way, the times and ſeaſons of the year blend themſelves together by diſorder and confuſed mixture, the winds breathe out their laſt gaſp, the clouds yield no rain, the earth be defeated of heavenly influence, and her

her fruits pine away as children at the withered breaſts of their mother, no longer able to yield them relief; what would become of man himſelf, whom all thoſe things do now ſerve? And how would he look back on thoſe benefits, for which, when they were daily poured upon him in boundleſs profuſion, he forgot to be thankful?

LECTURE XXXIX.

AN EXPLANATION OF THE PHENOMENA OF THE PLANETS, ACCORDING TO THE COPERNICAN SYSTEM.

I SHALL here define again ſome words which I have already explained, and recal your attention to ſome circumſtances which I have mentioned in a former Lecture. Theſe repetitions will not, I hope, be an object of complaint, as they will render this Lecture more perfect, and anſwer the beneficial purpoſe of grounding you more firmly in the ſcience we are now treating.

The line that a planet deſcribes round the ſun is called it's *orbit*; the motion of all the planets in their orbits is from weſt by the ſouth to the eaſt; this is called their *annual* motion.

The orbits of the planets are not all in the ſame plane. but in planes inclined to each other, or interſecting each other at different angles. The orbit of the earth is taken as a ſtandard, from whence their reſpective inclinations are computed.

The planes of the ſeveral orbits of the planets produced to the fixed ſtars, mark the ſeveral circles which each planet would appear to deſcribe in the ſphere of the heaven to a ſpectator placed in the ſun; theſe circles may be called the *heliocentric orbits* of the planets.

The heliocentric orbit of the earth is the *ecliptic*: to a ſpectator in the ſun, the earth will appear

pear to go round the ſun in the ecliptic eaſtward in twelve months.

We may ſuppoſe as many great circles as we pleaſe to be deſcribed upon the ſphere of the heavens, interſecting one another at the poles of the ecliptic, and cutting it at right angles; theſe are termed *ſecondaries of the ecliptic*, and *circles of latitude.* The *latitude* of a planet or ſtar is it's diſtance from the ecliptic, meaſured in degrees, &c. upon a circle of latitude paſſing through the ſtar or planet.

The latitude a planet would appear to have, when viewed from the ſun, is it's *heliocentric latitude;* that which it appears to have to an inhabitant of the earth, is called it's *geocentric latitude.*

By the place of a planet is meant the place of it's center; it's geocentric place is that where it appears to an inhabitant of the earth.

The two points where the ecliptic is cut by the heliocentric orbit of a planet, are the nodes of the planet. The *aſcending* node ☊, is the point where the ecliptic is cut by the planet, before it deviates northward therefrom. The *deſcending* node ☋, is the point where the planet cuts the ecliptic before it deviates ſouthward.

When any planet has paſſed it's aſcending node, it deviates more and more northward till it is got ninety degrees from the node, then it is at it's utmoſt heliocentric northern latitude, or northern limit; from thence it continually approaches the ecliptic till it comes to ☋, after paſſing which it deviates more and more ſouthward, till it is 90 degrees from this node, when it is at it's ſouthern limit, or utmoſt ſouthern heliocentric latitude, which from thence continually decreaſes till the planet returns again to the aſcending node. A planet ſeen from the earth, only appears in the ecliptic, when it is in one of it's nodes.

The equator cuts the ecliptic in two opposite points: when the sun appears in one of these points, it is our *vernal*; when in the other, it is our *autumnal equinox*. The point of the vernal equinox is counted the first point of the ecliptic, because spring begins the *astronomical year*; this point is marked ♈ Aries.

The *longitude* of a celestial object is the number of degrees, &c. contained upon the ecliptic, reckoning from ♈ eastward, to the point where a circle of latitude drawn through the object cuts the ecliptic. The longitude and latitude of an object being given, it's place in the sphere of the heavens is known; and it's place is usually expressed, by saying it is in such a degree and minute of such a sign, and in such latitude.

A planet is said to be in *conjunction* with the sun, when it's geocentric place is very near the geocentric place of the sun; that is, when the sun is between our earth and the planet, or when the planet is between the earth and the sun.

A planet is said to be in *opposition*, when it's geocentric place is opposite to the geocentric place of the sun; that is, when the earth is between the sun and the planet.

An exact or central conjunction or opposition can happen only when a planet is in one of it's nodes; it is, however, usual to term it a conjunction or opposition, when the same secondary of the ecliptic passes through the sun or any planet, though the planet has latitude.

When the geocentric place of a planet is a quarter of a circle distant from the geocentric place of the sun, the planet is said to be in *quadrature*.

A planet is said to be *direct*, when it's geocentric motion is eastward; *retrograde*, when westward; *stationary*, when it's geocentric place continues the same for some time.

The

The diſtance an inferior planet ſeen from the earth appears to be from the ſun, is called it's *elongation*.

OF THE CONJUNCTIONS AND ELONGATIONS OF THE INFERIOR PLANETS, MERCURY AND VENUS.

There are two different ſituations, in which an *inferior* planet will appear in conjunction with the ſun; one when the planet is between the ſun and the earth, the other when the ſun is between the earth and the planet.

Let A, *fig.* 2, *pl.* 6, be the earth in it's orbit, E the place of Venus in E H G her orbit, S the ſun, F V P Q R T D an arc in the ſtarry heaven.

In the ſituation of things repreſented in this diagram, the ſun and Venus will appear in the ſame point of the heavens, and ſo be in conjunction. If Venus be at G, there will alſo be a conjunction. When the planet is at E, nearer to the earth than the ſun, it is called it's *inferior conjunction*; but when the planet is at G, farther from the earth than the ſun, it is termed the *ſuperior conjunction* of the planet.

When the planet is either at E or G, it has no elongation; but as the planet moves from E to y, it's elongation increaſes; for when it is at y, it appears in the line A y P, while the ſun appears in the line A S Q; ſo that P A Q will be the angular meaſure of it's elongation or diſtance from the ſun. When the planet arrives at x, it appears in the line A x V, which is a tangent to it's orbit, and then V A Q is the angular meaſure of it's elongation; which is the greateſt that can be on that ſide the ſun, for after this the elongation decreaſes. When the planet is at K, it's elongation is P A Q; when at G, it is nothing, becauſe it is then in it's ſuperior conjunction; as the planet moves on from

G, it's elongation again increafes; for when it comes to C, it appears in the line A C R, and it's elongation is R A Q. When the planet comes to H, a line drawn from the earth through the planet is a tangent to the orbit, and the elongation is T A Q, the greateft it can have when it is on the other fide of the fun; for after this, the elongation again decreafes.

Hence it is clear, that the inferior planets can never appear far from the fun, but muft always accompany it in it's apparent motion through the ecliptic. When we fee either Venus or Mercury, it is either in an evening, in the weft, foon after the fun has fet; or in a morning, a little before the fun rifes. Venus is indeed bright enough fometimes to be feen in the day-time, but then fhe is never far from the fun. The greateft elongation of Venus is about 40, and of Mercury about 33 degrees.

If the earth be at A, *fig.* 2, *pl.* 6, when Venus appears in any part of the arc E x G, fhe is *weftward* from the fun, and therefore rifes before him in the morning, and is called the *morning ftar*. When fhe appears any where in the arc G H E, fhe is *eaftward* from the fun, and therefore fets after him, is feen in the evening, and is called the evening ftar.

FALSITY OF THE PTOLEMAIC SYSTEM.

From the apparent motion of the inferior planets, we derive an argument to fhew the falfity of the Ptolemaic fyftem. If the earth was within the orbit of Venus, as this fyftem fuppofes, fhe might be fometimes on one fide the earth whilft the fun was on the oppofite fide; in other words, Venus might be fometimes in oppofition; but *Venus is never feen in oppofition*, therefore the earth is not within

within the orbit of Venus, and consequently the Ptolemaic system is not true. The same reasoning applies to Mercury.

OF THE RETROGRADE, STATIONARY, AND DIRECT MOTIONS OF MERCURY AND VENUS.

It is easy, on the *Copernican* system, to explain why the inferior planets appear to move sometimes in one direction, sometimes in a contrary one, and at other times to be stationary; for it is the natural result of the respective situations and motions of the earth and these planets. But on the Ptolemaic system, it is inexplicable without calling in the aid of a very complicated hypothesis.

When the inferior planets are passing from their greatest elongation, on one side of the sun, through their superior conjunction, to their greatest elongation on the other side, their motion, as viewed from the earth, is *direct*. In order to explain this proposition, we shall first suppose the earth to be at rest at A, *fig*. 2, *pl*. 6, and correct this supposition afterwards, by shewing that the apparent motion of Venus, or Mercury, seen from the earth, is the same in this respect, whether the earth moves in it's orbit, or rests at A.

The proposition to be explained is this: that as Venus, for instance, moves from x, it's greatest elongation on one side of the sun, through G it's superior conjunction, to H it's greatest elongation on the other side, it will appear to a spectator upon the earth, to move from west to east according to the order of the signs; that is, it's *geocentric motion will be direct*.

The planets move round the sun from west to east, and consequently if there was a spectator at the sun, they would appear to him to move through the zodiac, according to the order of the

 signs;

ſigns; or in other words, the heliocentric motion of Venus is direct. Now if the ſun and the earth A, are both on the ſame ſide of the planet, a ſpectator at the earth is in the ſame ſituation with reſpect to the planet and it's motion, as if he had been at the ſun: for whilſt the planet is moving from x, through G to H, a ſpectator either at A or S is on the concave ſide of the planet's orbit; and conſequently the planet will appear to move in the ſame manner from either; but the apparent motion of the planet, when ſeen from the ſun, is direct, and conſequently it's motion, when ſeen from the earth, *will alſo be direct.*

When Venus is at x, it appears to a ſpectator on the earth at A, to be in the line A x V, or is ſeen among the ſtars at V; when Venus has moved to K, it is ſeen among the fixed ſtars at P; when it has moved to G, it is in it's ſuperior conjunction; when it has moved to C, it appears among the fixed ſtars at R; and when it is come to K, it appears among the fixed ſtars at T. Thus whilſt Venus has moved in it's orbit from x, it's greateſt elongation on one ſide of the ſun, through G it's ſuperior conjunction, to H it's greateſt elongation on the other ſide, it appears to have deſcribed the arc V P Q R T in the concave ſphere of the heavens; but the letters x K G C H lie from weſt to eaſt, becauſe they lie in the ſame direction that the planet moves round the ſun; and the letters V P Q R T lie in the ſame direction with x K G C H. Therefore, as the planet ſeems to a ſpectator on the earth, to deſcribe the arc V P Q R T, it's apparent motion, ſeen from the earth, *is direct*, or from weſt to eaſt.

As the inferior planets move from their greateſt elongation on one ſide of the ſun, through their inferior conjunction, to their greateſt elongation on the other ſide, their geocentric motion is *retrograde.*

Whilſt

Whilſt Venus, for inſtance, is moving from it's greateſt elongation H, through it's inferior conjunction E, to it's other greateſt elongation x, it appears to a ſpectator upon the earth at A, to move backwards, or from eaſt to weſt, contrary to the order of the ſigns.

A ſpectator at the ſun is on the concave ſide of the planet's orbit. But whilſt Venus is moving from it's greateſt elongation H on one ſide, through E it's inferior conjunction, to x it's greateſt elongation on the other ſide, a ſpectator upon the earth is on the convex ſide of it's orbit.

Therefore, if a ſpectator at the ſun S would ſee the planet move one way, a ſpectator at the earth A will ſee it move the contrary way; or the geocentric motion will be contrary to it's heliocentric motion, and therefore retrograde; for as ſeen from the ſun, it's motion is always direct.

That two ſpectators, one at the earth, the other at the ſun, as they are on contrary ſides of the arc H E x, will ſee the planet apparently move contrary ways, may be rendered more plain by the following familiar conſideration. If two men ſtand with their faces towards each other, and a ball is rolled along upon the ground, this ball will move from the right hand of one of the men towards his left, and from the left hand of the other towards his right. In like manner, if one man is at the earth A, and the other at the ſun S, then whilſt the planet is deſcribing the arc H e x which is between them, it will appear to move from the right hand of the man at S towards his left, and from the left hand of the man at A towards his right.

Whilſt the motion of Venus is direct, or while it is deſcribing the arc x G H, it appears to move from V to T, among the fixed ſtars. But after it has been carried in it's orbit from H to Q, it appears in the line A z R, and is ſeen among the fixed

ſtars at R. When it comes to E, it appears at Q; and when at y, it's apparent place in the heavens is at P. Thus as the planet paſſes from it's greateſt elongation H on one ſide of the ſun, through it's inferior conjunction E, to it's greateſt elongation x on the other ſide, *it apparently runs back from* T *to* V.

Venus is *ſtationary*, or has no apparent motion for ſome time, when it is at it's greateſt elongation; that is, when it is at H or x, and it's apparent place is either at T or V.

When either of the inferior planets, Venus for inſtance, is at it's greateſt elongation H or x, a line drawn from the earth through the planet, as A H T, or A x V, is a tangent to the orbit. Now though a right line touches a circle but in one point, yet ſome part of the circle greater than a point is ſo near to the tangent, as not to be diſtinguiſhed from it. Thus the arc b d ſo nearly coincides with the tangent A H T, that a ſpectator's eye placed at A, could not diſtinguiſh the tangent from this part of the curve. Conſequently, while the planet is deſcribing this arc, no other change will be made in it's geocentric place, than if it was to move in the tangent.

But the geocentric place of the planet would not be altered, if the planet was to move in the tangent. For if it was to move from T towards A, or from A to V, the apparent place of it in the heavens would in one caſe be at T, in the other caſe at V. Therefore, while the planet is at it's greateſt elongation, and is deſcribing a ſmall arc in it's orbit, that nearly coincides with the tangent, it's geocentric place does not alter, but it appears to continue for ſome time in the ſame part of the heavens, or is *ſtationary*.

We have hitherto ſuppoſed the earth to be at reſt, and upon that ſuppoſition have explained the progreſs and regreſs, the conjunctions and ſtations of

of the inferior planets. If this ſuppoſition was true, V T, or the arc which the planet at any time deſcribes in it's progreſs, and T V, the arc which it deſcribes in it's regreſs, would always be in the ſame part of the heavens. The planet, when in conjunction, would always appear at Q among the ſame fixed ſtars; and at it's elongation, or when it is ſtationary, it would always appear among the ſame fixed ſtars T on one ſide of the ſun, and at V on the other ſide.

But this ſuppoſition is not true; for the earth revolves in it's orbit A B O round the ſun. Now if the earth is at A, the time of either conjunction, the planet at this conjunction would appear among the fixed ſtars at Q, and the arcs of the greateſt elongation Q V and Q T, would be on each ſide of thoſe ſtars. But if the earth is at B, at the time of either of the conjunctions, then at the time of this conjunction, the planet will appear in the line B S T, and be ſeen among the fixed ſtars at T, and the arcs of the greateſt elongation will be on each ſide of theſe ſtars; that is, the conjunctions and elongations will happen in a different part of the heavens, when the earth is at B, from what they happen when the earth is at A. In other reſpects, the foregoing phenomena will be much the ſame, notwithſtanding the motion of the earth, only the planet will be more direct in the fartheſt part of the orbit, and leſs retrograde in the neareſt.

The direct and retrograde motion is ſometimes ſwifter, ſometimes ſlower. The direct motion is ſwifteſt, when the ſun is between us and the planet; their retrograde ſwifteſt, when they are between us and the ſun.

When an inferior planet, viewed from a ſuperior, moves apparently retrograde, the ſuperior planet has alſo a retrograde motion.

When a ſuperior planet, viewed from an inferior,

ferior, appears ſtationary, the inferior planet viewed at the ſame time from the ſuperior is alſo ſtationary.

OTHER APPEARANCES OF THE INFERIOR PLANETS.

The inferior planets, it is plain from what I have ſhewn you, always appear very near the ſun. But from the motion of the earth, the ſun appears in different parts of the heavens in different times of the year; conſequently, as the inferior planets are always very near the ſun, they will appear in different parts of the heavens at different times of the year; and their conjunctions, &c. will happen ſometimes in one part of the heavens, ſometimes in another part.

Venus, ſeen from the earth, appears to vibrate in an arc, half of which is on one ſide of the ſun's apparent place, half on the other.

Venus has been ſeen ſometimes moving acroſs the ſun's diſk in the form of a round black ſpot, with an apparent diameter of about fifty-nine ſeconds.

It has been found by obſervation, that the orbit of Venus is an ellipſe, having the ſun in one focus.

The upper apſis of the orbit is called the *aphelion*, the lower apſis is called the *perihelion*, of Venus. The line of the apſides has a ſlow motion eaſtward, at the rate of 2 degrees, 44 minutes, 46 ſeconds in a century. The nodes of Venus move weſtward about 31 ſeconds in a year.

Venus moves in her orbit, ſo as to deſcribe round the ſun areas proportional to the times.

OF

Of the Phases of Venus.

That the planets are opake bodies, and ſhine only by the light they receive from the ſun, is plain, becauſe they are not viſible in ſuch parts of their orbits as are between the ſun and earth, that is, when their illuminated ſide is turned from us.

The line in the planet's body, which diſtinguiſhes the lucid from the obſcure part, appears ſometimes ſtrait, ſometimes crooked. The convex part of the curve is ſometimes towards the ſplendid part, and the concave ſide towards that which is obſcure; and *vice verſa*, according to the ſituation of the planet with reſpect to the eye and the ſun.

The inferior planets going round the ſun in leſs orbits than our earth does, will ſometimes have more, ſometimes leſs of their illuminated ſide towards us; and as it is the illuminated part only which is viſible to us, Mercury and Venus will, through a good teleſcope, exhibit the ſeveral appearances of the moon, from a fine thin creſcent to the enlightened hemiſphere.

If we view Venus through a teleſcope, when ſhe follows the ſun's rays on the eaſtern ſide, and appears above the horizon after ſun-ſet, we ſhall ſee her appear nearly round, and but ſmall; ſhe is at that time beyond the ſun, and preſents to us an enlightened hemiſphere. As ſhe departs from the ſun towards the eaſt, ſhe augments in her apparent ſize; and on viewing her through a teleſcope, is ſeen to alter her figure, abating of her apparent roundneſs, and appearing ſucceſſively like the moon, in the different ſtages of her decreaſe. At length, when ſhe is at her greateſt elongation, ſhe is like the moon in her firſt quarter, and appears as ſhe does when from a full ſhe has decreaſed to half a moon.

After

After this, as ſhe approaches (in appearance) to the ſun, ſhe appears concave in her illuminated part, as the moon when ſhe forms a creſcent; thus ſhe continues till ſhe is hid entirely in the ſun's rays, and preſents to us her whole dark hemiſphere, as the moon does in her conjunction, no part of the planet being then viſible.

When ſhe departs out of the ſun's rays on the weſtern ſide, we ſee her in the morning, juſt before day-break. It is in this ſituation that Venus is called the morning ſtar, as in the other ſhe is called the evening ſtar. She at this time appears very beautiful, like a fine thin creſcent: juſt a verge of ſilver light is ſeen on her edge. From this period ſhe grows more and more enlightened every day, till ſhe is arrived at her greateſt digreſſion or elongation, when ſhe again appears as a half moon, or as the moon in her firſt quarter; from this time, if continued to be viewed with a teleſcope, ſhe is found to be more and more enlightened, though ſhe is all the while decreaſing in magnitude, and thus continues growing ſmaller and rounder, till ſhe is again hid or loſt in the ſun's rays.

Fig. 1, *pl.* 8, repreſents the orbits of Venus and the earth, with the ſun in the center of them. The planet Venus is drawn in eight different ſituations, with it's illuminated hemiſpheres towards the ſun. If we ſuppoſe the earth to be at T, when Venus is at A, her dark hemiſphere is towards the earth, and ſhe is therefore inviſible, except the conjunction happens in her node, for then ſhe appears like a dark ſpot upon the diſc of the ſun. When Venus is at B, a little of her enlightened ſide is turned towards the earth, and therefore ſhe appears ſharp-horned; when ſhe is at C, half her enlightened hemiſphere is turned towards the earth, and ſhe appears like an half moon; at D, more than half her enlightened hemiſphere is towards

towards us, and ſhe appears like the moon about three days before it is full; at E, the whole enlightened hemiſphere is towards the earth. Venus is then either behind the ſun, or ſo very near him, that ſhe can hardly be ſeen; but if ſhe could, ſhe would appear round like the full moon. At F ſhe is like the moon three days after the full; at G like a half moon again; at H like a creſcent, with the points of the horns turned the contrary way to what they were at B. All this is equally applicable to Mercury.

Fig. 2, *pl.* 8, exhibits the different appearances of Venus, correſponding to her ſeveral ſituations in the foregoing figure; thus when Venus is at A, *fig.* 1, ſhe is quite dark, as at A, *fig.* 2; when ſhe is at B, *fig.* 1, ſhe appears as at B, *fig.* 2, &c.

The inferior planets do not ſhine brighteſt when they are full; thus Venus does not appear brighteſt in her ſuperior conjunction, though her illuminated hemiſphere be then turned towards us. Her ſplendor is more diminiſhed by her being at a greater diſtance from us, than the conſpicuous part of her illuminated diſc is increaſed. Dr. Halley has ſhewn, that Venus is brighteſt when her elongation from the ſun is about 40 degrees. Mercury is in his greateſt brightneſs, when very near his utmoſt elongation.

OF MERCURY.

The planet Mercury reſembles Venus in all the circumſtances of her apparent motion, and we make ſimilar inferences with reſpect to the real motions. His orbit is an ellipſe, having the ſun in one focus. The apſides move eaſtward 1 degree, 57 minutes, 20 ſeconds in a century; the nodes move

move weſtward 45 ſeconds in a year; and areas are deſcribed proportional to the times.

OF THE SUPERIOR PLANETS.

The ſuperior planets exhibit phenomena conſiderably different from thoſe exhibited by Mercury and Venus.

They come to our meridian both at noon and midnight; when they come to our meridian at noon, and are in the ecliptic, they are never ſeen croſſing the ſun's diſc.

They are always retrograde when in oppoſition, and direct when in conjunction.

I have already obſerved to you, that the greateſt elongation of either of the inferior planets is leſs than 90 degrees, or a quarter of a circle; ſo that they are never far from the ſun, but conſtantly attend it. But the ſuperior planets do not always accompany the ſun, as the inferior ones do: they are indeed ſometimes in conjunction with it, but then they are alſo ſometimes in *oppoſition* to, or 180 degrees from it.

To be more particular, let S, *fig.* 3, *pl.* 6, be the ſun; A B C D the orbit of any ſuperior planet, Mars, for inſtance; E F G the earth's orbit. If the earth be at E, the ſun at S, and the planet at D, the ſun and the planet will be both on the ſame ſide of the earth; and conſequently the planet will appear in conjunction with the ſun. But as the orbit of the earth is between the ſun and the orbit of the ſuperior planet, it is poſſible for the earth to be between the ſun and the planet, and conſequently for the planet and the ſun to be on oppoſite ſides of the earth, or the planet to be in oppoſition; thus, if when the earth is at E, Mars be at A, he is then in oppoſition to the ſun.

A ſupe-

A ſuperior planet is in *quadrature* with the ſun, when it's geocentric place is 90° from the geocentric place of the ſun; thus if the earth be at E, and Mars at B or C, he is in quadrature with the ſun; for the lines A E, E B, form a right angle, as do alſo the lines E A, E C.

OF THE DIRECT, STATIONARY, AND RETROGRADE MOTION OF THE SUPERIOR PLANETS.

As the earth goes round the ſun in leſs time, and in a leſs orbit than any of the ſuperior planets, it will not be amiſs to ſuppoſe a ſuperior planet to ſtand ſtill in ſome part of it's orbit, while the earth goes once round the ſun in her's, and conſider the appearances the planets would then have, which are theſe: 1. While the earth is in her moſt diſtant ſemicircle, the apparent motion of the planet would be *direct*. 2. While the earth is in her neareſt ſemicircle, the planet would be *retrograde*. 3. While the earth is near the points of contact of a line drawn from the planet, ſo as to be a tangent to the earth's orbit, the planet would be *ſtationary*.

To illuſtrate this, let A B C D E F G H, *pl.* 7, *fig.* 1, be the orbit of the earth, S the ſun, P Q O V the orbit of Mars, L M N T an arc of the ecliptic. Let us ſuppoſe the planet Mars to continue at P, while the earth goes round in her orbit, according to the order of the letters A B C, &c. A B C D E F G H may be conſidered as ſo many ſtations, from whence an inhabitant of the earth would view Mars at different times of the year; and if ſtrait lines be drawn from each of theſe ſtations, through Mars at P, and continued to the ecliptic, they will point out the apparent place of Mars, at theſe different ſtations.

Thus ſuppoſing the earth at A, the planet will be ſeen among the ſtars at L; when the earth is arrived

rived at B, the planet will appear at M; and in the ſame manner when at C D and E, it will be ſeen among the ſtars at N R T; therefore, while the earth moves over the large part of the orbit A B C D E, the planet will have an apparent motion from L to T, and this motion is from weſt to eaſt, or the ſame way with the earth; and the planet is ſaid to move *direct*, or according to the order of the ſigns. When the earth is near to A and E, the point of contact of the tangent to the earth's orbit, the planet will be *ſtationary* for a ſhort ſpace of time.

When the earth moves from E to H, the planet ſeems to return from T to N; and while it moves from H to A, it will be *retrograde* to L, where it will again be ſtationary: and ſince the part of the orbit which the earth deſcribes in paſſing from A to E, is much greater than the part E H P, though the ſpace T L which the planet deſcribes in direct and retrograde motion is the ſame, the direct motion from L to T muſt be much ſlower than the retrograde motion from T to L.

When the earth is at C, a line drawn from C through S and P to the ecliptic, ſhews that Mars is then in conjunction with the ſun. But when the earth is at H, a line drawn from H through P, and continued to the ecliptic, would terminate in a point oppoſite to S; therefore in this ſituation Mars would be in oppoſition to the ſun. Thus it appears that the motion of Mars is direct when in conjunction, and retrograde when in oppoſition.

The retrograde motions of the ſuperior planets happen oftener, the ſlower their motions are; as the retrograde motions of the inferior planets happen oftener, the ſwifter their angular motions; becauſe the retrograde motions of the ſuperior planets depend upon the motions of the earth; but thoſe of the inferior on their own angular motion. A

ſuperior

ſuperior one is retrograde once in each revolution of the earth; an inferior one in every revolution of it's own.

OTHER PHENOMENA OF THE SUPERIOR PLANETS.

The ſuperior planets are ſometimes nearer the earth than at other times; they alſo appear larger, or ſmaller, according to their different diſtances from us. Thus ſuppoſe the earth to be at C; if Mars be at P, he is the whole diameter of the earth's orbit nearer to us, than if he were at V, and conſequently his diſc muſt appear larger at V than it would be at P. In other places, the diſtances of Mars from the earth are intermediate.

The ſuperior planets going round the ſun in larger orbits than the earth, turn much the greater part of their enlightened hemiſphere towards it, and therefore appear round like the full moon, except Mars, who ſometimes appears like the moon at a little diſtance from the full.

They alſo move in an ellipſe, having the ſun in the center; the areas deſcribed are proportional to the times.

They are ſometimes nearer to, ſometimes further from the earth, and their apparent diameter is found to vary according to the difference in their diſtance.

OF THE SECONDARY PLANETS, OR SATELLITES.

As the moon turns round the earth, enlightening our nights, by reflecting the light ſhe receives from the ſun, ſo do other ſatellites enlighten the planets to which they belong; and as it keeps company with the earth in it's annual revolution round the ſun, ſo do they ſeverally accompany the

planets

planets to which they belong in their several courses round that luminary. Jupiter has four satellites, Saturn seven, the Georgium Sidus two.

The existence of all the satellites except the moon would have been unknown to us without the use of the telescope.

The satellites are distinguished according to their places, into first, second, &c. the first being that which is nearest the planet.

The satellites revolve round their primaries in elliptic orbits, the primary planets being in the focus.

The orbits of all Jupiter's satellites are nearly but not exactly in the same plane, which produced makes an angle with the plane of Jupiter's orbit of about 3°. The second deviates a little from the rest.

The planes of the orbits of the secondary planets produced, intersect the heliocentric orbits of their primaries in two opposite points, which are called their nodes. The planes of the orbits of the satellites of Jupiter and Saturn produced, intersect the ecliptic in two opposite points: these points of intersection, to distinguish them from the other, may be called the *geocentric* nodes of the satellites. The orbits of Jupiter and Saturn are so small in comparison of the sphere of the fixed stars, that the places of their satellites nodes are not sensibly altered by their primaries being in different parts of their orbits.

The orbits of all Saturn's satellites, except the 5th, which deviates from the rest several degrees, are nearly in the same plane. They are nearly parallel to the plane of the equator. The orbit of Saturn's 5th satellite makes an angle with the orbit of his primary of 13° 8′.

A satellite in one of it's nodes, seen from it's primary, appears in the orbit of it's primary: in all

all other parts of it's orbit, it has latitude ſeen from it's primary.

Every circle, whoſe plane produced paſſes through the eye, appears a ſtrait line: every circle viewed obliquely will appear an ellipſis, more or leſs wide, according as the eye is more or leſs elevated above the plane of the circle. The orbit of a ſatellite ſeen from the earth, when it's primary's heliocentric place is in his ſatellite's true node, and the earth in it's geocentric node, appears a ſtrait line: when the primary is in any other part of his orbit, the ſatellite's orbit will appear an ellipſis, whoſe ſhorteſt axis increaſes, the further the primary is from the node of the ſatellite.

The earth's orbit is ſo ſmall in compariſon of the orbits of Jupiter and Saturn, that whatever part of her orbit the earth is in, when theſe planets are in their ſatellites true nodes, their ſatellites will appear to deſcribe lines very near to ſtrait ones.

When a ſatellite is in it's ſuperior ſemicircle, *i. e.* that which is furtheſt from the earth, it's geocentric motion is direct: when in it's inferior ſemicircle, *i. e.* that neareſt our earth, it's geocentric motion is retrograde. Both theſe motions ſeem quickeſt, when the ſatellite is neareſt the center of the primary, and ſlower when they are more diſtant; at the greateſt diſtance they appear ſtationary for a ſhort time.

Since the diſtance of Jupiter and Saturn from our earth is very great, and our eye is never elevated much above the planes of their orbits, every ſatellite of Jupiter or Saturn ſeen from our earth, will appear always near it's primary, and to have an oſcillatory motion, ſometimes in a ſtrait line, ſometimes in an elliptic curve, going from it's primary, and returning to it again, firſt on one ſide, and then on the other. The ſatellites of Jupiter

or

or Saturn will ſometimes be hid from us by their primary, ſometimes paſs between us and their primary, ſometimes a ſatellite will paſs between us and another ſatellite.

The ſatellites and their primaries mutually eclipſe each other, but there are three caſes in which the ſatellites diſappear to us.

The one is, when the ſatellite is directly behind the body of it's primary, with reſpect to the *earth*; this is called an *occultation* of the planet.

Another is, when it is directly behind it's primary, with reſpect to the *ſun*, and ſo falls into it's ſhadow, and ſuffers an eclipſe, as the moon, when the earth is interpoſed between that and the ſun.

The laſt is, when it is interpoſed between the earth and it's primary; for then it cannot be diſtinguiſhed from the primary itſelf.

It is not often that a ſatellite can be diſcovered upon the diſc of Jupiter, even by the beſt teleſcopes, excepting at it's firſt entrance, when by reaſon of it's being more directly illuminated by the rays of the ſun, than the planet itſelf, it appears like a lucid ſpot upon it; ſometimes however a ſatellite is ſeen paſſing over the diſc like a dark ſpot; this has been attributed to ſpots on the ſurface of the ſatellite, and that the more probably as the ſatellite has been known to paſs over the diſc at one time as a dark ſpot, and at another time to be ſo luminous as only to be diſtinguiſhed from the planet at it's ingreſs and egreſs. The beginnings and endings of theſe eclipſes are eaſily ſeen by a teleſcope, when the planet is in a proper ſituation; but when it is in conjunction with the ſun, the brightneſs of that luminary renders both the planet and the ſatellite inviſible.

By obſerving the eclipſes of Jupiter's ſatellites, it was diſcovered that light is not propagated

gated inſtantaneouſly, though it moves with an incredible velocity; ſo that light reaches from the ſun to us in the ſpace of eleven minutes of time, at more than the rate of 100,000 miles in a ſecond.

The orbits of all the ſatellites of Saturn, except the fifth, are nearly in the ſame plane, which plane makes an angle with that of Saturn's orbit, of about 31°; this inclination is ſo great, that they cannot paſs either acroſs Saturn or behind it, with reſpect to the earth, except when they are very near their nodes, ſo that their eclipſes are not near ſo frequent as thoſe of Jupiter. An occultation of the fourth behind the body of Saturn has been obſerved, and Caſſini once ſaw a ſtar covered by the fourth ſatellite, ſo that for 13 minutes they appeared as one.

They are ſo minute as not to be viſible unleſs the air is exceeding clear; Caſſini obſerved the fifth ſatellite to diminiſh in ſize, as it went through the eaſtern part of it's orbit, until it became quite inviſible, while in the weſtern part it increaſed in brightneſs, until it arrived at it's greateſt ſplendor. In 1705 it was viſible in all parts of it's orbit, though the ſame teleſcopes were often uſed before to diſcover it without ſucceſs.

The Georgium Sidus is attended by two ſatellites.

The following table ſhews their general affections.

SECONDARY PLANETS.

			Diſtance from it's Primary. English Miles.	Synodical Revolutions round it's Primary.	Days	Hours	Min.	Sec.	Proportion of Bulk with reſpe[ct] to the Earth.
JUPITER's Four SATELLITES.	1,	or Innermoſt	269,105	—	1	18	28	36	1/8
	2	— —	428,312	—	3	13	17	54	1/8
	3	— —	683,071	—	7	3	59	36	About 1/7
	4	— —	1,201,386	—	16	18	5	7	1/8
SATURN's Seven SATELLITES.	1	diſcovered in 1789, by Dr. Herſchel.	126,000	—	—	22	40	46	
	2		162,000	—	1	8	53	9	
	3	———	195,671	—	1	21	18	27	
	4	———	250,631	—	2	17	44	22	
	5	———	350,099	—	4	12	25	12	
	6	———	811,610	—	15	22	34	38	
	7	———	2,365,222	—	79	7	47	—	

Ring of Saturn 21,000 Miles broad, and 21,000 Miles diſtant from his Body on all Sides. Thickneſs of the Ring unknown.

GEORGIAN's SATELLITES.	1	diſcovered 11 Jan. 1787, by Dr. *Herſ.*	About 289,118	—	8	16	51	9
	2		About 387,505	—	13	11	6	46

OF

OF THE MOON'S MOTION.

You have ſeen that four of the primary planets are attended in their revolutions by ſecondary planets; we are in like manner attended by the moon, ſhe enlightens our nights, by reflecting the light ſhe receives from the ſun, as the other ſatellites enlighten the planets to which they ſeverally belong.

If you imagine the plane of the moon's orbit to be extended to the ſphere of the heaven, it would mark therein a great circle, which may be called the moon's apparent orbit; becauſe the moon appears to the inhabitants of the earth to move in that circle, through the twelve ſigns of the zodiac, in a periodical month. This poſition is illuſtrated by *fig.* 3, *pl.* 9; let E F G H I be the orbit of the earth, S the ſun, a b c d the orbit of the moon, when the earth is at E: let A B C D be a great circle in the ſphere of the heaven, in the ſame plane with the moon's orbit. The moon, by going round her orbit according to the order of letters, appears to an inhabitant of the earth to go round in the great circle A B C D, according to the order of thoſe letters: for when the moon is at a, ſeen from the earth at E, ſhe appears at A; when the moon is got to b, ſhe appears at B; when to c, ſhe will appear at C; when arrived at d, ſhe will appear at D. It is true, when the moon is at b, the viſual line drawn from E, through the moon, terminates in L; as it does in M, when the moon is at d; but the lines L M and D B being parallel, and not farther diſtant from each other than the diſtance of the earth's orbit, are as to ſenſe coincident, their diſtance meaſured in the ſphere of the heaven being inſenſible; for the ſame reaſon, though the earth moves from E to F, in the time that the

moon goes round her orbit, ſo that at the end of a periodical month the moon will be at a, and is ſeen from the earth at F, in the line F N; the moon will, notwithſtanding, appear at A, the lines F N and E A being parallel, and as to ſenſe coincident: in like manner, in whatever part of her orbit the earth is, as at H or I, the moon, by going round in her orbit, will appear to an inhabitant of the earth to go round in the great circle A B C D.

The plane of the moon's orbit produced till it cuts the plane of the ecliptic, makes an angle with it of about 5°: this angle is ſometimes more, ſometimes leſs then 5°. The points where the moon's orbit produced cuts the ecliptic, are called the moon's nodes; and her aſcending ☊ the dragon's head, her deſcending node ☋ the dragon's tail. The moon's nodes have a ſlow motion of 19° 22′ in a year, which carries them round the ecliptic, contrary to the order of the ſigns, in 19 years.

The *line of the moon's node* is a line drawn from one node to the other.

The extremities of the line of the nodes are not always directed towards the ſame points of the ecliptic, but continually ſhift their places from eaſt to weſt, or contrary to the order of the ſigns, performing an entire revolution about the earth, in the ſpace of ſomething leſs than nineteen years.

The moon appears in the ecliptic only when ſhe is in one of her nodes: in all other parts of her orbit ſhe is either in north or ſouth latitude, ſometimes nearer to, ſometimes further removed from the ecliptic, according as ſhe happens to be more or leſs diſtant from the nodes.

When the place, in which the moon appears to an inhabitant of the earth, is the ſame with the ſun's place, ſhe is ſaid to be in *conjunction*. When the moon's place is oppoſite to the ſun's place, ſhe is

is ſaid to be in *oppoſition*. When ſhe is a quarter of a circle diſtant from the ſun, ſhe is ſaid to be in *quadrature*. Both the conjunction and oppoſition of the moon are termed *ſyzigies*.

The common lunar month, or the time that paſſes between any new moon and the next that follows it, is called *a ſynodical month*, or *a lunation*. This month contains 29 days, 12 hours, 44 minutes, 3 ſeconds.

The moon's motion in her orbit is conſidered abſolutely, or with relation to the ſun. The moon's motion in her orbit, which is alſo her motion in longitude, is ſometimes ſwifter, ſometimes ſlower; her mean motion is 13 degrees, 10 minutes, 35 ſeconds, in a day, which carries her round the zodiac in 27 days, 7 hours, 43 minutes. The time wherein the moon is carried round the zodiac is called a *periodical month*; or a *periodic month* is the time in which the moon performs one entire revolution about the earth, from any point in the zodiac to the ſame again; and contains 27 days, 7 hours, 43 minutes.

The moon's motion conſidered with relation to the ſun is called her elongation from the ſun. The moon's motion from the ſun is the exceſs of the velocity of the moon's motion, above the velocity of the ſun's apparent motion; in the ecliptic, this exceſs is ſometimes more, ſometimes leſs. The moon's mean motion from the ſun is 12 degrees, 11 minutes, 26 ſeconds, in a day, which carries the moon from one conjunction with the ſun to another in 29 days, 12 hours, 44 minutes, 3 ſeconds. The time between any conjunction and the conjunction immediately following, as before obſerved, is called *a ſynodical month*, or *a lunation*, wherein the moon appears in all her phaſes.

If the earth had no revolution round the ſun, or the ſun no apparent motion in the ecliptic, the

the periodical and ſynodical month would be the ſame; but as this is not the caſe, the moon takes up a longer time to paſs from one conjunction to the next, than to deſcribe it's whole orbit; or the time between one new moon and the next, is longer than the moon's periodical time.

The moon going round our earth in an orbit whoſe ſemidiameter is leſs than the neareſt diſtance of any planet, may come between our eye and any planet or ſtar that is near the ecliptic. The time when the moon appears to touch a planet or ſtar, is called *it's appulſe*, which being inſtantaneous, ſerves to determine the longitude of different places where it is obſerved.

The moon revolves round the earth from weſt to eaſt, and the ſun apparently revolves round the earth the ſame way. Now at the new moon, or when the ſun and moon are in conjunction, they both ſet out from the ſame place, to move the ſame way round the earth; but the moon moves much faſter than the ſun, and conſequently will overtake it; and when the moon does overtake it, it will be a new moon again. If the ſun had no apparent motion in the ecliptic, the moon would come up to it, or be in conjunction again, after it had gone once round in it's orbit; but as the ſun moves forward in the ecliptic, whilſt the moon is going round, the moon muſt move a little more than once round, before it comes even with the ſun, or before it comes to conjunction. Hence it is that the time between one conjunction, and the next in ſucceſſion, is ſomething more than the time the moon takes up to go once round it's orbit; or a ſynodical month is longer than a periodical one.

In *fig.* 3, *pl.* 8, let S be the ſun, C F a part of the earth's orbit, M D a diameter of the moon's orbit when the earth is at A, and m d another

diameter

diameter parallel to the former, when the earth is at B. Whilſt the earth is at A, if the moon be at D, ſhe will be in conjunction; and if the earth was to continue at A, when the moon had gone once round it's orbit, from D through M, ſo as to return to D again, it would again be in conjunction. Therefore, upon the ſuppoſition that the earth has no motion in it's orbit, the periodical and ſynodical months would be equal to one another. But as the earth does not continue at A, it will move forwards in it's orbit, during the revolution of the moon from A to B: and as the moon's orbit moves with it, the diameter M D will then be in the poſition m d; therefore, when the moon has deſcribed it's orbit, it will be at d in this diameter m d; but if the moon is at d, and the ſun at S, the moon will not be in conjunction, conſequently the periodical month is completed before the ſynodical. The moon, in order to come to conjunction, when the earth is at B, muſt be at e, in the diameter e f; or beſides going once round in it's orbit, it muſt alſo deſcribe the arc d e. The ſynodical month is, therefore, longer than the periodical, by the time the moon takes up to deſcribe the arc d e.

This may be alſo explained in another manner, by conſidering the motion of the ſun; a view of the ſubject, that may render it more eaſy to ſome young minds than the foregoing. Thus let us ſuppoſe the earth at reſt at E, *fig.* 4, *pl.* 8, M the moon in conjunction with the ſun at S, while the moon deſcribes her orbit A B C about the earth at E, let the ſun advance by his apparent annual motion from S to D. It is plain that the moon will not come in conjunction with the ſun again, till, beſides deſcribing her orbit, ſhe hath deſcribed, over and above, the arch M F, correſponding to the arch S D.

As the moon goes round the earth in a much ſmaller

ſmaller orbit than that in which the earth revolves round the ſun, ſometimes more, ſometimes leſs, and ſometimes no part of her enlightened half will be towards us; hence ſhe is inceſſantly varying her appearance; ſometimes ſhe looks full upon us, and her viſage is all luſtre, ſometimes ſhe ſhews only half her enlightened face, ſoon ſhe appears as a radiant creſcent, in a little time all her brightneſs vaniſhes, and ſhe becomes a beamleſs orb.

The full moon, or oppoſition, is that ſtate in which her whole diſc is enlightened, and we ſee it all bright, and of a circular figure. The new moon is when ſhe is in conjunction with the ſun; in this ſtate, the whole ſurface turned towards us is dark, and ſhe is therefore inviſible to us.

The firſt quarter of the moon ſhe appears in the form of a ſemicircle, whoſe circumference is turned towards the weſt. At the laſt quarter, ſhe appears again under the form of a ſemicircle, but with the circumference turned towards the eaſt.

The moon is generally inviſible a day or two before and after conjunction, and the obſcure light viſible in the moon a little before and after conjunction is reflected upon her from the earth.

Theſe phaſes may be illuſtrated in a very pleaſing manner, by expoſing an ivory ball to the ſun, in a variety of poſitions, by which it may preſent a greater or ſmaller part of it's illuminated ſurface to the obſerver. If it be held nearly in oppoſition, ſo that the eye of the obſerver may be almoſt immediately between it and the ſun, the greateſt part of the enlightened ſide will be ſeen; but if it be moved in a circular orbit, towards the ſun, the viſible enlightened part will gradually decreaſe, and at laſt diſappear, when the ball is held directly towards the ſun. Or to apply the experiment more immediately to our purpoſe; if the ball, at any time

time when the ſun and moon are both viſible, be held directly between the eye of the obſerver and the moon, that part of the ball on which the ſun ſhines, will appear exactly of the ſame figure as the moon itſelf.

The phaſes of the moon, like thoſe of Venus, may alſo be illuſtrated by a diagram; thus in *fig.* 1, *pl.* 9, let S be the ſun, T the earth, A B C D E F G H the orbit of the moon. The firſt obſervation to be deduced from this figure, is, that the half of the earth and moon which is towards the ſun, is wholly enlightened by it; and the other half, which is turned from it, is totally dark. When the moon is in conjunction with the ſun at A, her enlightened hemiſphere is turned towards the ſun, and the dark one towards the earth; in which caſe, we cannot ſee her, and it is ſaid to be new moon. When the moon has moved from A to B, a ſmall portion a b of her enlightened hemiſphere will be turned towards the earth; which portion will appear of the form repreſented at B, *fig.* 2, *pl.* 9, (a figure which exhibits the phaſes as they appear to us).

As the moon proceeds in her orbit, according to the order of the letters, more and more of her enlightened part is turned towards the earth. When ſhe arrives at C, in which poſition ſhe is ſaid to be in quadrature, one half of that part towards the earth is enlightened, appearing as at C among the phaſes; this appearance is called a half moon. When ſhe comes to D, the greateſt part of that half which is towards us is enlightened; the moon is then ſaid to be gibbous, and of that figure which is ſeen at D, in *fig.* 2.

When the moon comes to F, ſhe is in oppoſition to the ſun, and conſequently turns all her illuminated ſurface towards the earth, and ſhines with a full face, for which reaſon ſhe is called a full

full moon. As ſhe paſſes through the other half of her orbit, from E by F G, and H to A again, ſhe puts on the ſame phaſes as before, but in a contrary order or poſition.

As the moon, by reflected light from the ſun, illuminates the earth, ſo the earth does more than repay her kindneſs, in enlightening the ſurface of the moon, by the ſun's reflex light, which ſhe diffuſes more abundantly upon the moon, than the moon does upon us; for the ſurface of the earth is conſiderably greater than that of the moon, and conſequently if both bodies reflect light in proportion to their ſize, the earth will reflect much more light upon the moon than it receives from it.

In the new moon, the illuminated ſide of the earth is fully turned towards the moon, and the Lunarians will have a full earth, as we, in a ſimilar poſition, have a full moon. And from thence ariſes that dim light which is obſerved in the old and new moons, whereby, beſides the bright and ſhining horns, we can perceive the reſt of her body behind them, though but dark and obſcure. Now when the moon comes to be in oppoſition to the ſun, the earth, ſeen from the moon, will appear in conjunction with him, and it's dark ſide will be turned towards the moon, in which poſition the earth will be inviſible to the Lunarians; after this, the earth will appear to them as a creſcent. In a word, the earth exhibits the ſame appearance to the inhabitants of the moon, that the moon does to us.

The moon turns about it's own axis in the ſame time that it moves round the earth; it is on this account that ſhe always preſents nearly the ſame face to us: for by this motion round her axis, ſhe turns juſt ſo much of her ſurface conſtantly towards us, as by her motion about the earth would

be

be turned from us. This motion about her axis is equable and uniform, but that about the earth is unequal and irregular, as being performed in an ellipſis; conſequently the ſame preciſe part of the moon's ſurface can never be ſhewn conſtantly to the earth; which is confirmed by a teleſcope, by which we often obſerve a little ſegment on the eaſtern and weſtern limb, appear and diſappear by turns, as if her body librated to and fro; this phenomenon is called the moon's *libration.* The lunar motions are ſubject to ſeveral other irregularities, which are fully diſcuſſed in the larger works on aſtronomy.

LECTURE XL.

Of Eclipses.

THOSE phenomena that are termed eclipfes, were in former ages beheld with terror and amazement, and looked upon as prodigies that portended calamity and mifery to mankind. Thefe fears, and the erroneous opinions which produced them, had their fource in the hieroglyphical language of the firft inhabitants of the earth. We do not, however, imagine that even the moft ancient of thefe knew any more of the laws and motions of the heavenly bodies, than what could be difcovered from immediate fight; or that they knew enough of the lunar fyftem to calculate an eclipfe, or even that they ever attempted it.

The word *eclipfe* is derived from the Greek, and fignifies dereliction, a fainting away, or fwooning. Now as the moon falls into the fhadow of the earth, and is deprived of the fun's enlivening rays, at the time of her greateft brightnefs, and even appears pale and languid before her obfcuration, lunar eclipfes were called *lunæ labores*, the ftruggles or labours of the moon; to relieve her from thefe imagined diftreffes, fuperftition adopted methods as impotent as they were abfurd.

When the moon, by paffing between us and the fun, deprived the earth of it's light and heat, the fun was thought to turn away his face, as if in abhorrence of the crimes of mankind, and to threaten everlafting night and deftruction to the world.

world. But thanks to the advancement of ſcience, which, while it has delivered us from the fooliſh fears and idle apprehenſions of the ancients, leaves us in poſſeſſion of their repreſentative knowledge, enables us to explain the appearances on which it was founded, and points out the perverſion and abuſe of it.

Any opake body that is expoſed to the light of the ſun, will caſt a ſhadow behind it. This ſhadow is a ſpace deprived of light, into which if another body comes, it cannot be ſeen for want of light; the body thus falling within the ſhadow, is ſaid to be *eclipſed*.

The earth and moon being opake bodies, and deriving their light from the ſun, do each of them caſt a ſhadow behind, or towards the hemiſphere oppoſed to the ſun. Now when either the moon or the earth paſſes through the other ſhadow, it is thereby deprived of illumination from the ſun, and becomes inviſible to a ſpectator on the body from whence the ſhadow comes; and ſuch ſpectator will obſerve an eclipſe of the body which is paſſing through the ſhadow; while a ſpectator on the body which paſſes through the ſhadow, will obſerve an eclipſe of the ſun, being deprived of his light.

Hence there muſt be three bodies concerned in an eclipſe; 1. the luminous body; 2. the opake body, that caſts the ſhadow; and 3. the body involved in theſhadow.

Of Eclipses of the Moon.

As the earth is an opake body, enlightened by the ſun, it will caſt a ſhadow towards thoſe parts that are oppoſite to the ſun, and the axis of this ſhadow will always be in the plane of the ecliptic, becauſe both the ſun and the earth are always there.

The ſun and the earth are both ſpherical bodies; if they were, therefore, of an equal ſize, the ſhadow of the earth would be cylindrical, as in *fig.* 5, *pl.* 8, and would continue of the ſame breadth at all diſtances from the earth, and would conſequently extend to an infinite diſtance, ſo that Mars, Jupiter, or Saturn, might be eclipſed by it; but as theſe planets are never eclipſed by the earth, this is not the ſhape of the ſhadow, and conſequently the earth is not equal in ſize to the ſun.

If the ſun were leſs than the earth, the ſhadow would be wider, the farther it was from the earth, ſee *fig.* 6, *pl.* 8, and would therefore reach to the orbits of Jupiter and Saturn, and eclipſe any of theſe planets when the earth came between the ſun and them; but the earth never eclipſes them, therefore this is not the ſhape of it's ſhadow, and conſequently the ſun is not leſs than the earth.

As we have proved that the earth is neither larger nor equal to the ſun, we may fairly conclude that it is leſs; and that the ſhadow of the earth is a cone, which ends in a point at ſome diſtance from the earth, ſee *fig.* 7, *pl.* 8.

The axis of the earth's ſhadow falls always upon that point of the ecliptic that is oppoſite to the ſun's geocentric place; thus if the ſun be in the firſt point of Aries, the axis of the earth's ſhadow will terminate in the firſt point of Libra. It is clear, therefore, *that there can be no eclipſe of the moon but when the earth is interpoſed between it and the ſun*, that is, *at the time of it's oppoſition, or when it is full*; for unleſs it is oppoſite to the ſun, it can never be in the earth's ſhadow: and if the moon did always move in the plane of the ecliptic, ſhe would every full moon paſs through the body of the ſhadow, and there would be a total eclipſe of the moon.

We have already obſerved, that the moon's orbit

orbit is inclined to the plane of the ecliptic, and only coincides with it in two places, which are termed the nodes. It may, therefore, be full moon * without her being in the plane of the ecliptic; ſhe may be either on the north or the ſouth ſide of it; in either of theſe caſes, ſhe will not enter into the ſhadow, but be above it in the one, below it in the other.

To illuſtrate this, let H G, *fig.* 1, *pl.* 10, repreſent the orbit of the moon, E F the plane of the ecliptic, in which the center of the earth's ſhadow always moves, and N the node of the moon's orbit; A B C D four places of the ſhadow of the earth in the ecliptic. When the ſhadow is at A, and the moon at I, there will be no eclipſe; when the full moon is nearer the node, as at K, only part of her globe paſſes through the ſhadow, and that part becoming dark, it is called a *partial eclipſe*; and it is ſaid to be of ſo many *digits* as there are *twelve parts* of the moon's diameter darkened. When the full moon is at M, ſhe enters into the ſhadow C, and paſſing through it becomes wholly darkened at L, and leaves the ſhadow at O; as the whole body of the moon is here immerſed in the ſhade, this is called a *total eclipſe*. But when the moon's center paſſes through that of the ſhadow, which can only happen when ſhe is in the node at N, it is called a *total and central eclipſe*. There will always be ſuch eclipſes, when the center of the moon, and axis of the ſhadow, meet in the nodes.

 The

* A planet may be in oppoſition to, or conjunction with the ſun, without being in a right line that paſſes through the ſun and the earth. Aſtronomers term it in conjunction with the ſun, if it be in the ſame part of the zodiac; in oppoſition, if it be in a part of the zodiac, 180 degrees from the ſun.

The duration of a central eclipſe is ſo long, as to let the moon go the length of three of it's diameters totally eclipſed, which ſtay in the earth's ſhadow is computed to be about four hours; whereof the moon takes one hour from it's beginning to enter the ſhadow, till quite immerſed therein; two hours more ſhe continues totally dark; and the fourth hour is taken up from her firſt beginning to come out of the ſhadow, till ſhe is quite out of it.

From the magnitude of the ſun, the ſize of the earth, their diſtance from each other, the refraction of the atmoſphere, and the diſtance of the moon from the earth, it has been calculated, that the ſhadow of the earth terminates in a point, which does not reach ſo far as the moon's orbit. The moon is not, therefore, eclipſed by the ſhadow of the earth alone. The atmoſphere, by refracting ſome of the rays of the ſun, and reflecting others, caſts a ſhadow, though not ſo dark a one as that which ariſes from an opake body; when, therefore, we ſay that the moon is eclipſed, by paſſing into the ſhadow of the earth, it is to be underſtood of the ſhadow of the earth, together with it's atmoſphere. Hence it is that the moon is viſible in eclipſes, the ſhadow caſt by the atmoſphere not being ſo dark as that caſt by the earth. The cone of this ſhadow is larger than the cone of the earth's ſhadow, the baſe thereof broader, the axis longer. There have been eclipſes of the moon, in which the moon has entirely diſappeared: Hevelius mentions one of this kind, which happened in Auguſt 1647, when he was not able to diſtinguiſh the place of the moon, even with a good teleſcope, although the ſky was ſufficiently clear for him to ſee the ſtars of the fifth magnitude.

All opake bodies, when illuminated by the rays of the ſun, caſt a ſhadow from them, which is encompaſſed by a *penumbra*, or thinner ſhadow, which every

where ſurrounds the former, growing larger and larger as we recede from the body; in other words, the penumbra is all that ſpace ſurrounding the ſhadow, into which the rays of light can only come from ſome part of that half of the globe of the ſun, which is turned towards the planet, all the reſt being intercepted by the intervening body.

Let S, *fig.* 2, *pl.* 10, be the ſun, E the planet, then the penumbral cone is F G H. The nearer any part of the penumbra is to the ſhadow, the leſs light it receives from the ſun; but the further it is, the more it is enlightened; thus the parts of the penumbra near M are illuminated by thoſe rays of light, which come from that part of the ſun near to I, all the reſt being intercepted by the planet E; in like manner, the parts about N can only receive the light that comes from the part of the ſun near to L, whereas the parts of the penumbra at P and Q are enlightened in a much greater degree: for the planet intercepts from P only thoſe rays which come from the ſun near L, and hides from Q only a ſmall part of the ſun near I.

The moon paſſes through the penumbra before ſhe enters into the ſhadow of the atmoſphere; this cauſes her gradually to loſe her light, which is not ſenſible at firſt, but as ſhe goes into the darker part of the penumbra, ſhe grows paler; the penumbra, where it is contiguous to the ſhadow, is ſo dark, that it is difficult to diſtinguiſh one from the other. If the atmoſphere be ſerene, every eclipſe of the moon is viſible at the ſame inſtant to all the inhabitants of that ſide of the earth to which ſhe is oppoſite.

If we imagine a plane parallel to the baſe of the earth's conical ſhadow to paſs through the ſhadow at the diſtance of the moon's center from the earth, there will be projected upon the plane, the circle of the earth's ſhadow, ſurrounded with

the circle of the penumbra: the center of thofe circles is always in the plane of the ecliptic. The circle of the earth's fhadow, when the earth is at the fame diftance from the fun, is greater, the nearer the moon is to the earth. The circle of the earth's fhadow is greater, when the moon is at the fame diftance from the earth, the further the earth is from the fun. The apparent femidiameter of the moon in her fyzygies is about 15 minutes: the femidiameter of the circle of the earth's fhadow, is about three times as great as the femidiameter of the moon.

If the moon in oppofition be in the node, the eclipfe of the moon will be total and central: if very near the node, total, but not central: if fo far from the node that only part falls into the fhadow, the eclipfe is partial: if fo far from the node, that the diftance of her center from the center of the circle of the earth's fhadow is greater than the femidiameter of the fhadow added to the femidiameter of the moon, fhe will not be eclipfed at all. The moon paffes through the penumbra before fhe falls into the fhadow; this makes her gradually lofe her light, and grow paler, a little before fhe begins to be eclipfed.

The moon is fometimes in the middle of a total eclipfe invifible in fome places, and not in others, becaufe of the different conftitution of the air; but generally fhe appears of a dufky red colour, efpecially towards the edges, being more dark about the middle of the fhadow: this reddifh colour is owing to the rays of the fun, or to the light of the fun's atmofphere refracted through the earth's atmofphere, or to the light of the ftars and planets, moft probably to the firft of thefe.

The fun or moon feen from the earth, or the earth feen from the fun or moon, though fpherical, on account of their diftance appear like circular planes:

planes: these circular planes are called the disks of the sun, earth, or moon. The apparent diameter of the disk of the sun or moon is by astronomers divided into 12 equal parts, which are called digits; each digit into 60 parts, which are called minutes; as many of these digits and minutes as are covered by the shadow in the middle of a partial lunar eclipse, so many digits and minutes of the moon are said to be eclipsed. In a total eclipse of the moon without continuance, the moon is eclipsed 12 digits: in a total eclipse with continuance, she is eclipsed more than 12; thus, if her whole disk is immersed so deep within the shadow, that if her diameter contained 15 such parts as now it contains 12 of, the whole 15 would be eclipsed, the moon is then eclipsed 15 digits. Sometimes the apparent diameter of the moon is observed near the time of the eclipse, and the greatness of the eclipse expressed in minutes of degrees and seconds.

The motion of the moon in her orbit being eastward, the beginning of a lunar eclipse is when the eastern limb or edge of the moon's disk touches the western limb of the shadow: the end of a lunar eclipse when the western limb of the moon's disk leaves the eastern limb of the shadow: in a total eclipse, the time the whole disk is in the shadow is called the stay, or time of total immersion.

The beginning or end of a lunar eclipse, being instantaneous, serves to discover the longitude, but not accurately without a telescope; for by reason of the penumbra, the beginning appears too soon, the end too late to the naked eye, and not at the same time to all eyes: for this reason the longitudes of places and the places of the moon determined by eclipses, before the invention of telescopes, cannot be depended upon. The mo-

derns, that they may have a greater number of opportunities of determining the longitude than the beginnings and endings of eclipſes would afford, do it by obſerving the immerſions of the moſt remarkable ſpots of the moon into the ſhadow, or by their emerging out of it.

The quantity of a lunar eclipſe depends, 1*ſt*, upon the largeneſs of the circle of the earth's ſhadow, whoſe diameter may be different: 2*dly*, upon the apparent diameter of the moon, which may be different: 3*dly*, *cæteris paribus*, upon the diſtance of the moon from her node, at the moment of her being at the full.

The duration of a lunar eclipſe depends partly upon it's quantity, partly upon the velocity of the moon's motion croſs the ſhadow, which is the ſame as her motion from the ſun. The moon's motion from the ſun is ſwifteſt when ſhe is in her *perigee*, and the duration of a central eclipſe will then be ſhorteſt, though the moon's diameter and the diameter of the circle of the earth's ſhadow be then greateſt; becauſe the exceſs of the moon's way through the ſhadow, is more than compenſated by the greater velocity of the moon's motion. The longeſt duration of a central lunar eclipſe, *i. e.* when the earth is *in aphelion*, and the moon *in apogee*, is about 3 hours, 57 minutes, 6 ſeconds. The ſhorteſt duration of a central lunar eclipſe, *i. e.* when the earth is *in perihelion*, and the moon *in perigee*, is 3 hours, 37 minutes, 26 ſeconds.

OF ECLIPSES OF THE SUN.

The moon, when in conjunction, if near one of her nodes, will be interpoſed between us and the ſun, and will conſequently hide the ſun, or a part of him, from us, and caſt a ſhadow upon the earth:

earth: this is called an *eclipse of the sun*; it may be either partial or total.

An eclipse of any lucid body, is a deficiency or diminution of light, which would otherwise come from it to our eye, and is caused by the interposition of some opake body.

The eclipses of the sun and moon, though expressed by the same word, are in nature very different; the sun, *in reality, loses nothing of it's native lustre in the greatest eclipses*, but is all the while incessantly sending forth streams of light every way round him, as copiously as before. Some of these streams are, however, intercepted in their way towards our earth, by the moon coming between the earth and the sun: and the moon having no light of her own, and receiving none from the sun on that half of the globe which is towards our eye, must appear dark, and make so much of the sun's disk appear so, as is hid from us by her interposition.

What is called an eclipse of the sun, is therefore, in reality, an eclipse of the earth, which is deprived of the sun's light, by the moon's coming between, and casting a shadow upon it. The earth being a globe, only that half of it which at any time is turned towards the sun, can be enlightened by him at that time; it is upon some part of this enlightened half of the earth, that the moon's shadow, or penumbra, falls in a solar eclipse.

The sun is always in the plane of the ecliptic; but the moon being inclined to this plane, and only coinciding with it at the nodes, it will not cover either the whole or a part of the sun; or in other words, the sun will not be eclipsed, unless the moon at that time is in or near one of her nodes.

The moon, however, cannot be directly between

tween the ſun and us, unleſs they are both in the ſame part of the heavens; that is, unleſs they are in conjunction. Therefore, the ſun can never be eclipſed but at the new moon, nor even then, unleſs the moon at that time is in or near one of her nodes.

The moon being much ſmaller than the earth, and having a conical ſhadow, becauſe ſhe is leſs than the ſun, can only cover a ſmall part of the earth by her ſhadow; though, as we have obſerved before, the whole body of the moon may be involved in that of the earth. Hence an eclipſe of the ſun is viſible but to a few inhabitants of the earth; whereas an eclipſe of the moon may be ſeen by all thoſe that are on that hemiſphere which is turned towards it. In other words, as the moon can never totally eclipſe the earth, there will be many parts of the globe that will ſuffer no eclipſe, though the ſun be above their horizon.

An eclipſe of the ſun always begins on the weſtern, and ends on the eaſtern ſide; becauſe the moon moving in her orbit from weſt to eaſt, neceſſarily firſt arrives at and touches the ſun's weſtern limb, and goes off at the eaſtern.

It is not neceſſary, in order to conſtitute a *central* eclipſe of the ſun, that the moon ſhould be exactly in the line of the nodes, at the time of it's conjunction; for it is ſufficient to denominate an eclipſe of the ſun *central*, that the center of the moon be directly between the center of the ſun, and the eye of the ſpectator; for to him, the ſun is then centrally eclipſed. But as the ſhadow of the moon can cover but a ſmall portion of the earth, it is obvious this may happen when the moon is not in one of her nodes. Further, the ſun may be eclipſed centrally, totally, partially, and not at all, at the ſame time.

A total

A total eclipſe of the ſun is a very curious ſpectacle: Clavius ſays that, in that which he obſerved in Portugal, in 1650, the obſcurity was greater, or more ſenſible than that of the night: the largeſt ſtars made their appearance for about a minute or two, and the birds were ſo terrified, that they fell to the ground.

Thus in *fig.* 3, *pl.* 10, let A B C be the ſun, M N the moon, h l g part of the cone of the moon's ſhadow; f d the penumbra of the moon: from this figure it is eaſy to perceive,

1. That thoſe parts of the earth that are within the circle repreſented by g h, are covered by the ſhadow of the moon, ſo that no rays can come from any part of the ſun into that circle, on account of the interpoſition of the moon.

2. In thoſe parts of the earth where the penumbra falls, only part of the ſun is viſible; thus between d and g, the parts of the ſun near C cannot be ſeen, the rays coming from thence towards d or g, being intercepted by the moon: whereas at the ſame time, the parts between f and h are illuminated by rays coming from C, but are deprived by the moon of ſuch as come from A.

3. The nearer any part of the earth, within the penumbra, is to the ſhadow of the moon, as in places near g, l, or h, the leſs is the portion of the ſun viſible to it's inhabitants; the nearer it is to the outſide of the penumbra, as towards d, e, or f, the greater is the portion ſeen.

4. Out of the penumbra the entire diſk is viſible.

The quantity of a ſolar eclipſe in general is according to the ſize of the moon's ſhade projected upon the earth; this ſhade is largeſt when the earth is in *aphelion*, the moon in *perigee*.

The quantity of a ſolar eclipſe to thoſe within the line which the center of the moon's ſhade de-
ſcribes

ſcribes upon the earth, depends upon the apparent diameters of the ſun and moon; if they be exactly equal, the eclipſe will be barely total; if the diameter of the moon be greater than the ſun, it will be more than total; if the diameter of the moon's ſhade be leſs than the ſun's, the eclipſe will be annular, i. e. the ſun's diſk will not be entirely covered, but there will be a ring of his light viſible round the diſk of the moon.

Eclipſes may be alſo total or annular, in places a little diſtant from the way of the center of the ſhade, but not central. More than total eclipſes appear greateſt in thoſe places which are neareſt the path of the center of the ſhadow. Partial eclipſes appear greateſt in thoſe places which are neareſt the way of the moon's ſhadow upon the earth. The quantity of a ſolar eclipſe in any place is eſtimated by the number of digits of the ſun's diameter covered by the diſk of the moon, in the middle of the eclipſe: in an eclipſe barely total, the ſun is eclipſed 12 digits: when the eclipſe is more than total, he is eclipſed ſo much more than 12 digits, as the diſtance between the limbs of the diſks of the ſun and moon amounts to in thoſe points where thoſe limbs are neareſt to each other.

The ſhape of the moon's ſhadow projected upon the earth in the middle of the eclipſe, depends upon the moon's diſtance from her node. If the moon is in her node, the centers of the ſun, moon, and earth, are all in a ſtrait line, which is perpendicular to the ſpherical ſurface of the earth, and therefore the projection of the moon's ſhadow upon the diſk of the earth will be a circle. When the moon has latitude, the axis of her ſhadowy cone makes an oblique angle to the ſpherical ſurface of the earth, and therefore the projection of the ſhadow upon the earth's diſk will be an ellipſis, whoſe excen-

excentricity will be greater, the greater the moon's latitude is.

The largeneſs of the moon's ſhade projected upon the earth, depends upon the following circumſtances: the conical ſhadow of the moon is longer, and ſimilar ſections at equal diſtances from the moon are larger, the greater the moon's diſtance is from the ſun. Therefore the projection of the moon's ſhadow upon the earth is largeſt, when the earth is in *aphelion*, and the moon in *perigee*; leaſt, when the earth is in *perihelion*, and the moon in *apogee*, at the ſame time. In a ſolar eclipſe that is central and barely total, the *vertex* of the moon's ſhadow does but juſt reach the ſurface of the earth; in an annular eclipſe, the conical ſhadow of the moon does not reach ſo far as the earth.

The way of the moon's ſhadow upon the earth is generally from weſt to eaſt; inclining towards the north pole, if the moon is near her aſcending node; towards the ſouth pole, if ſhe is near her deſcending node. The way of the ſhadow upon the earth may ſometimes, but rarely, be from eaſt to weſt, and the ſun appear to be eclipſed firſt near his eaſtern limb. The way of the center of the moon's ſhadow is a ſtrait line only when it deſcribes a diameter upon the earth's diſk; otherwiſe it is an elliptic curve, but ſo near a ſtrait line that it may without any ſenſible error be repreſented by one.

The duration of ſolar eclipſes depends on the following conſiderations. If the moon is in her node, the center of her ſhadow paſſes over the center of the earth's enlightened diſk, and deſcribes a diameter, i. e. the longeſt line which can be taken in a circle; if the moon has latitude, the center of her ſhadow deſcribes a chord in the circular diſk of the earth, i. e. a line leſs than a diameter:

The

The whole time the *penumbra* of the moon is paſſing over the diſk of the earth, is called the time of the general eclipſe: becauſe all that time the ſun appears eclipſed in ſome place of the earth or other. The beginning of the general eclipſe is when the moon's *penumbra* enters upon the diſk of the earth, the end when the *penumbra* of the moon leaves the earth's diſk. The duration of the general eclipſe depends upon the length of the line deſcribed upon the earth's diſk by the center of the ſhadow, the velocity of the moon's motion from the ſun, and the largeneſs and ſhape of the projection of the ſhadow and *penumbra*.

The beginning of a ſolar eclipſe in any place upon the earth is when the *penumbra*, which ſurrounds the moon's ſhadow, firſt touches the place; the end of the eclipſe is when the *penumbra* leaves the place; the duration of the eclipſe is whilſt the *penumbra* paſſes over the place. In any place upon the earth where the eclipſe is more than total, the beginning of the total darkneſs is when the ſhadow of the moon firſt touches the place, the end when it leaves it. Eclipſes more than total are ſaid to be total with ſtay; the time of ſtay, viz. of total darkneſs, in any place, is the time of the ſhadow paſſing over that place.

The time the ſhadow is paſſing over any place, (and the ſame is true of the *penumbra*, which is always ſimilar to the ſhadow,) is variable, 1ſt, from the velocity of the moon's motion from the ſun; 2d, from the length of the ſhadow meaſured in a line parallel to the way of the ſhadow, and drawn through the place; 3d, from the proximity of the place to the center of the earth's diſk.

The circumference of the moon's orbit is 60 times as great as the circumference of the earth; and therefore, each degree of the moon's orbit is equal to 60 degrees of a great circle on the earth's ſurface.

ſurface. And as one degree of ſuch a circle on the earth contains $69\frac{1}{4}$ Engliſh miles, a degree of the moon's orbit contains 4155 miles. The moon's motion in her orbit, conſidering it as from the ſun to the ſun again, (or from change to change) is through all the 360 degrees thereof in $29\frac{1}{2}$ days; and therefore ſhe moves about half a degree, or 2077 miles from the ſun in one hour: and with the ſame velocity her ſhadow moves over the earth, namely, at the rate of $34\frac{6}{10}$ miles in a minute; which is more than four times as ſwift as the motion of a cannon-ball.

The moon goes round the earth, not in a circular, but in an elliptical orbit; and the earth's center is in one of the focuſes of that orbit. Hence the moon's diſtance from the earth is continually varying: at a mean rate it is 240,000 miles.

When the moon changeth at her leaſt diſtance from the earth, her dark ſhadow may cover a ſpot 170 miles broad on the earth's ſurface, if the time be about noon; but much more if the time be in the morning or evening: and, to all who are within that ſpot, the ſun will appear to be totally eclipſed, but to no place without it, although he will be partially eclipſed to ſeveral hundred miles around. But as the moon's motion is then the ſwifteſt that it can be, the dark ſhadow will be carried quite over that ſpot in five minutes at moſt, although the diurnal motion of the earth is the ſame way that the moon's ſhadow goes. And therefore, the longeſt duration of a total eclipſe of the ſun can never be more than 5 minutes, even if it happen at noon. In the morning and evening, the earth's motion contributes very little toward the duration of a ſolar eclipſe, becauſe the dark ſhadow falls ſo obliquely on the earth; and indeed, in ſuch an eclipſe, the darkneſs will be over in leſs than 5 minutes, although the ſhadow then covers

more

more of the earth's ſurface than it can do about noon.

When the moon changeth at her mean diſtance from the earth, the point of her dark ſhadow does but juſt reach the earth: and to the places where it goes ſucceſſively over, the ſun will be totally eclipſed only for an inſtant of time.

When the moon changeth at her greateſt diſtance from the earth, her dark ſhadow does not reach the earth at all: and therefore the ſun is not then totally hid from any part of the earth, but appears like a luminous ring, all around the dark body of the moon, to each part of the earth that the point of her ſhadow is ſucceſſively directed while ſhe is paſſing between the earth and the ſun.

Thus it is plain, that the ſun can never be eclipſed but at the time of new moon, nor the moon but when ſhe is full.

OF THE LIMITS OF SOLAR AND LUNAR ECLIPSES.

The earth goes round the ſun every year in an orbit called *the ecliptic;* and therefore the ſun, as ſeen from the earth, appears to go round the ecliptic once a year.

If the moon's orbit lay quite even with the ecliptic, (or, as it is commonly expreſſed, in the plane of the ecliptic) the ſun would be eclipſed at the time of every new moon, becauſe the moon would then be directly between the earth and the ſun: and the moon would be eclipſed at every time ſhe was full, becauſe the earth would then be directly between her and the ſun.

But one half of the moon's orbit lies on the north ſide of the plane of the ecliptic, and the other half on the ſouth ſide of it. Therefore the moon's orbit interſects the plane of the ecliptic only in *two* oppoſite points, which are called the

moon's

moon's nodes. The angle which the moon's orbit makes with the plane of the ecliptic is 5 degrees, 18 minutes; so that, when the moon is in the northmost point of her orbit, she is 5 degrees, 18 minutes north of the ecliptic; and as far south of it when she is in the southmost point of her orbit. Hence it is plain, that the moon can never be in the ecliptic but when she is in one or other of her nodes.

When the moon is any more than 18 degrees from either of her nodes at the time of her change, she does not pass between the sun and any part of the earth; but goes either above or below the sun, according as she is then north or south of the ecliptic; and therefore she cannot then hide any part of the sun from any part of the earth. But when she changeth within 18 degrees of either node, she will hide the whole or part of the sun from some part of the earth. And if she be in either of her nodes at the time of change, the sun will be centrally eclipsed to that point of the earth's surface which is then in a strait line between the sun's center and the earth's. At all other places which the center of the moon's shadow goes over, the sun will likewise be centrally eclipsed.

When the moon is any more than 12 degrees from either of her nodes at the time of full, she passeth clear of the earth's shadow; and therefore she cannot be eclipsed at that time. But when she is within 12 degrees of either node at the time of her being full, she is eclipsed. And when she is full in either of her nodes, she goes through the middle of the earth's shadow, and is totally eclipsed with the longest continuance, which may be above an hour and an half.

Of the Period of Eclipses.

The ecliptic is divided into twelve equal parts,

called *ſigns*, and each ſign into 30 equal parts called *degrees*. If the moon's nodes had no motion through the ſigns of the ecliptic, there would be juſt half a year between the times of the ſun's conjunctions with the nodes; and then, in whatever ſigns the ſun and moon were eclipſed in any given year, they would be eclipſed every year after. But the eclipſes fall ſo much ſooner every ſucceeding year than they did on the year before, as to prove that the nodes move backward, or contrary to the motion of the moon, $19\frac{1}{3}$ degrees every year, from the conſequent toward the antecedent ſigns. And therefore, they go backward through all the ſigns and degrees of the ecliptic in 18 years and 225 days.

If in that time there were any exact number of courſes of the moon from change to change, without any fraction, there would be an exact period or reſtitution of eclipſes in the ſame time. But during this revolution of the nodes, there are 230 courſes of the moon, and a quarter of a courſe more: ſo that there can be no exact period of eclipſes in any complete revolution of the nodes.

But in 18 years, 11 days, 7 hours, and $43\frac{1}{3}$ minutes, in which time there are juſt 223 courſes of the moon from change to change, there is a conjunction of the ſun and moon with the ſame node as before; and conſequently, a period or reſtitution of all the eclipſes of the ſun and moon. And therefore, if to the mean time of any eclipſe, either of the ſun or moon, you add 18 years, 11 days, 7 hours, $43\frac{1}{3}$ minutes, you will have the mean time of the return of that eclipſe. Only note, that when the laſt day of February, in leap-years, comes but four times into this period, you are to add the above number of days, hours, and minutes: but when it comes five times in, as it will ſometimes do, you muſt add one whole day leſs.

And

And thus, any one, who has a ſet of almanacks for 19 years, in which all the eclipſes are noted for that time, may very eaſily calculate the time of any future eclipſe. This is called the *Chaldean Saros*, or period of eclipſes.

As the nodes go backwards at the rate of $19\frac{1}{3}$ degrees every year, which, for the ſake of round numbers, we may call 19 degrees; theſe 19 degrees are nearly equal to 19 days of the ſun's motion, and the half of 19 is $9\frac{1}{2}$; ſubtract $9\frac{1}{2}$ days from $182\frac{1}{2}$ days, which make half a year, and there will remain 173 days for the time between the ſun's being in conjunction with either of the nodes till the time of his being ſo with the other.

Now, as the ſun can never be eclipſed when he is more than 18 degrees from either node, nor the moon when ſhe is more than 12, (as already mentioned,) it is plain there muſt be an eclipſe of the ſun at the time of every new moon that falls within 18 days before or after the time of his being in conjunction with either of the nodes; and that the moon muſt be eclipſed at every time of her being full within 12 days before or after the time of the ſun's being in conjunction with either of the nodes. And conſequently, if we can tell on what days of the year theſe conjunctions fall, we can eaſily tell at what new and full moons there muſt be eclipſes; ſeeing the days of new and full moons are ſo generally known.

In ſome years there are ſix eclipſes, four of which are of the ſun, and two of the moon: in other years there are only two, and when that happens, they are both of the ſun: but the moſt common number is four; namely, two of the ſun, and two of the moon.

THE DARKNESS AT OUR SAVIOUR'S CRUCIFIXION SUPERNATURAL.

From the account I have given you of eclipses it plainly appears, that the sun can never be eclipsed, in a natural way, but at the time of new moon, nor the moon but when she is full; and that, when the sun is totally eclipsed, the darkness can never continue above five minutes at any place of the earth.

But the three evangelists, St. *Matthew*, St. *Mark*, and St. *Luke*, mention a darkness that continued three hours, at the time of our SAVIOUR'S crucifixion. If their account of that darkness had been false, it would have been contradicted by many who were then present; especially as they were great enemies both to Christ and his few disciples, as well as to the doctrine he taught. But as none of the Jews have contradicted the evangelists' account of this most extraordinary phenomenon, it is plain that their account of it is true. Besides, the evangelists must have known full well, that it could not be their interest to palm such a lie upon mankind; which, when detected, must have gone a great way toward destroying the credibility of all the rest of the account they gave of the life, actions, and doctrine of their master: and instead of forwarding the belief of christianity, it would have been a blow at the very root thereof. We do not find that they have bestowed any panegyric on the life and actions of CHRIST, or thrown out an invective against his cruel persecutors; but, in the most plain, simple, and artless manner, have told us what their senses convinced them were matters of fact: so that we have as good reason to believe that there was such darkness, as we have to believe that Christ was then upon earth: and that

that he was, has never been contradicted, even by the Jews themſelves.

But there are other accounts of Chriſt, beſides thoſe which the evangeliſts have left us. It is expreſsly affirmed, by the two Roman hiſtorians, *Tacitus* and *Suetonius*, that there was a general expectation ſpread all over the eaſtern nations, that out of *Judea* ſhould ariſe a perſon who ſhould be Governor of the world. That there lived in *Judea*, at the time which the goſpel relates, ſuch a perſon as *Jeſus* of *Nazareth*, is acknowledged by all authors, both Jewiſh and Pagan, who have written ſince that time. The ſtar that appeared at his birth, and the journey of the Chaldean wiſe men, is mentioned by *Chalcidius* the Platoniſt. *Herod*'s cauſing the children in *Bethlehem* to be ſlain, and a reflection upon him on that occaſion by the emperor *Auguſtus*, is related by *Macrobius*. Many of the miracles that *Jeſus* wrought, particularly his healing the lame, and curing the blind, and caſting out devils, are owned by theſe inveterate and implacable enemies of chriſtianity, *Celſus* and *Julian*, and the authors of the Jewiſh Talmud. That the power of the heathen gods ceaſed, after the coming of Chriſt, is aaknowledged by *Porphyry*, who attributed it to their being angry at the ſetting up of the chriſtian religion, which he calls impious and profane. The crucifixion of Chriſt under *Pontius Pilate* is related by *Tacitus*, and the earthquake and miraculous darkneſs attending it were recorded in the public Roman regiſters, commonly appealed to by the firſt chriſtian writers, as what could not be denied by the adverſaries themſelves; and are in a particular manner atteſted by *Phlegon*, the freed man of *Adrian*.

Some people have ſaid, that the above-mentioned darkneſs might have been occaſioned by a

natural eclipſe of the ſun; and conſequently, that there was nothing miraculous in it. If this had been the caſe, it is plain that our Saviour muſt have been crucified at the time of new moon. But then, in a natural way, the darkneſs could not poſſibly have continued for more than five minutes: whereas, to have made it continue for three hours, the moon's motion in her orbit muſt have been ſtopt for three hours, and the earth's motion on it's axis muſt have been ſtopt as long too. And then, if the power of gravitation had not been ſuſpended during all that time, the moon would have fallen a great way toward the earth. So that nothing leſs than a triple miracle muſt have been wrought to have cauſed ſuch a long continued darkneſs by the interpoſition of the moon between the ſun and any part of the earth: which ſhews, that they who make ſuch a ſuppoſition are entirely ignorant of the nature of eclipſes. But there could be no natural or regular eclipſe of the ſun on the day of Chriſt's crucifixion; as the moon was full on that day, and conſequently in the ſide of the heavens oppoſite to the ſun. And therefore the darkneſs at the time of his *crucifixion* was quite *ſupernatural*.

The Iſraelites reckoned their months by the courſe of the moon, and their years (after they left *Egypt*) by the revolution of the ſun, computed from the equal day and night in ſpring to the like time again. For we find, they were told by the Almighty (Exod. xii. 2.) that the month *Abib* (or *Niſan*) ſhould be to them *the firſt month of the year*. This was the month in which they were delivered from their Egyptian bondage, and includes part of March and part of April, in our way of reckoning.

In ſeveral places of the Old Teſtament, we find that the Iſraelites were ſtrictly commanded to kill the paſchal lamb on the evening (or,

(or, as it is in the Hebrew, *between the evenings*) of the fourteenth day of the firſt month; and *Joſephus* expreſsly ſays, "The paſſover was kept on the fourteenth day of the month *Niſan*, according to the moon, when the ſun was in Aries." And the ſun always *enters* the ſign Aries, when the day and night are equal in the ſpring ſeaſon.

They began each month on the firſt day of the moon's being viſible, which could not be in leſs than 24 hours after the time of her change; and the moon is full on the 15th day reckoned from the time of change. Hence, the 14th day of the month, according to the Iſraelites' way of reckoning, was the day of full moon: which makes it plain, that the paſſover was always kept on a full moon day; and at the time of the full moon *next after* the equal day and night in the ſpring; or, when the ſun was *in* Aries.

All the four evangeliſts aſſure us, that our Saviour was crucified at the time of the paſſover: and hence it is plain, that the crucifixion was at the time of *full moon*, when it is impoſſible that the moon could hide the ſun from any part of the earth. St. John tells us, that Chriſt was crucified on the day that the paſſover was to be eaten; and we likewiſe find, that ſome remonſtrated againſt his being crucified "on the *feaſt day*, leſt it ſhould cauſe an uproar among the people."*

* Ferguſon's Aſtronomical Lecture on Eclipſes.

LECTURE XLI.

OF PARALLAX AND REFRACTION, AND THE ABERRATION OF LIGHT, &c.

ASTRONOMY is ſubject to many difficulties, beſides thoſe which are obvious to every eye. When we look at any ſtar in the heavens, we do not ſee it in it's real place; the rays coming from it, when they paſs out of the purer etherial medium, into our coarſer and more denſe atmoſphere, are *refracted*, or bent in ſuch a manner, as to ſhew the ſtar higher than it really is. Hence we ſee all the ſtars before they riſe, and after they ſet; and never, perhaps, ſee any one in it's true place in the heavens. There is another difference in the apparent ſituation of the heavenly bodies, which ariſes from the ſtations in which an obſerver views them. This difference in ſituation is called the *parallax* of an object.

OF REFRACTION.

As one of the principal objects of aſtronomy is to fix the ſituation of the ſeveral heavenly bodies, it is neceſſary, as a firſt ſtep, to underſtand the cauſes which occaſion a falſe appearance of the place of thoſe objects, and make us ſuppoſe them in a different ſituation from that which they really have. Among theſe cauſes, *refraction* is to be reckoned. By this term is meant, the bending of the rays of light as they paſs out of one medium into another.

The earth is every where ſurrounded by an hetero-

heterogeneous fluid, a mixture of air, vapour, and terreſtrial exhalations, that extend to the regions of the ſky. The rays of light from the ſun, moon, and ſtars, in paſſing to a ſpectator upon the earth, come through this medium, and are ſo refracted in their paſſage through it, that their apparent altitude is greater than their true altitude.

Let A C, *fig.* 3, *pl.* 7, repreſent the ſurface of the earth, T it's center, B P a part of the atmoſphere, H E K the ſphere of the fixed ſtars, A F the ſenſible horizon, G a planet, G D a ray of light proceeding from the planet to D, where it enters our atmoſphere, and is refracted towards the line D T, which is perpendicular to the ſurface of the atmoſphere; and as the upper air is rarer than that near the earth, the ray is continually entering a denſer medium, and is every moment bent towards T, which cauſes it to deſcribe a curve as D A, and to enter a ſpectator's eye at A, as if it came from E, a point above G. And as an object always appears in that line in which it enters the eye, the planet will appear at E, higher than it's true place, and frequently above the horizon A F, when it's true place is below it at G.

This refraction is greateſt at the horizon, and decreaſes very faſt as the altitude increaſes, inſomuch that the refraction at the horizon differs from the refraction at a very few degrees above the horizon, by about one-third part of the whole quantity. At the horizon, in this climate, it is found to be about 33 minutes. In climates nearer to the equator, where the air is purer, the refraction is leſs; and in the colder climates, nearer to the pole, it increaſes exceedingly, and is a happy proviſion for lengthening the appearance of the light at thoſe regions ſo remote from the ſun. Gaſſendus relates, that ſome Hollanders who wintered

tered in Nova Zembla, in latitude 75 degrees, were agreeably ſurprized with a ſight of the ſun 17 days before they expected him in the horizon. This difference was owing to the refraction of the atmoſphere in that latitude. To the ſame cauſe, together with the peculiar obliquity of the moon's orbit to the ecliptic, ſome of theſe very northern regions are indebted for an uninterrupted light from the moon much more than half the month, and ſometimes almoſt as long as it is capable of affording any light to other parts of the earth.

Through this refraction we are favoured with the ſight of the ſun, about 3 minutes and $\frac{1}{2}$ before it riſes above the horizon; and alſo as much every evening after it ſets below it, which in one year amounts to more than 40 hours.

It is to this property of refraction that we are alſo indebted for that enjoyment of light from the ſun when he is below the horizon, which produces the morning and evening twilight. The ſun's rays, in falling upon the higher part of the atmoſphere, are reflected back to our eyes, and form a faint light, which gradually augments till it becomes day. It is owing to this, that the ſun illuminates the whole hemiſphere at once; deprived of the atmoſphere, he would have yielded no light, but when our eyes were directed towards him; and even when he was in meridian ſplendor, the heavens would have appeared dark, and as full of ſtars as on a fine winter's night. The rays of light would have come to us in ſtrait lines, and the appearance and diſappearance of the ſun would have been inſtantaneous; we ſhould have had a ſudden tranſition from the brighteſt ſun-ſhine to the moſt profound darkneſs, and from thick darkneſs to a blaze of light. Thus by refraction we are prepared gradually for the light of the ſun,

the

the duration of it's light is prolonged, and the ſhades of darkneſs ſoftened.

To it we muſt alſo attribute another curious phenomenon, mentioned by Pliny; for he relates, that the moon had been eclipſed once in the weſt, at the ſame time that the ſun appeared above the horizon in the eaſt. Mæſtlinus, in Kepler, ſpeaks of another inſtance of the ſame kind, which fell under his own obſervation.

OF PARALLAX.

The *parallax* of a celeſtial object is the difference between the places that the object is referred to in the celeſtial ſphere, when ſeen at the ſame time from two different places within that ſphere. Or it may be conſidered as the angle under which any two places in the inferior orbits are ſeen, from a ſuperior planet, or from a fixed ſtar.

The parallaxes principally uſed by aſtronomy, are thoſe which ariſe from conſidering the object as viewed either from the center of the earth and the ſun, or from the ſurface and center of the earth, or from all three compounded.

The difference between the place of any planet as ſeen from the ſun, and the ſame planet as ſeen from the earth, is called *the parallax of the annual orbit*; in other words, it is the angle at any planet ſubtended between the ſun and the earth.

The *diurnal parallax* is the change of a celeſtial body's apparent place, ariſing from it's being viewed from two different ſtations, one on the *ſurface*, and the other at the *center* of the earth.

The neceſſity of this diſtinction is obvious, for you know that an object will change it's apparent ſituation with reſpect to another, according

to

to the ſtation from which it is viewed; hence celeſtial objects viewed from different parts of the earth's ſurface, will appear in different ſituations. To facilitate and give certainty to calculation, aſtronomers refer all celeſtial appearances to the center of the earth; of courſe they are obliged continually to calculate *parallaxes*, in order to reduce the obſerved places of the objects to that where they would be ſituated if ſeen from the center of the earth.

Let a line, A B, *fig.* 4, *pl.* 7, be drawn perpendicular to the diſtance B C, between an adjacent object C, and any given ſtation B: the apparent places of the object, when viewed from the extremities of the line A B, will be different.

1. The perpendicular line A B is called the baſe. 2. The extremities A B of the baſe are called ſtations. 3. The angle A C B, ſubtended by the extremities of the baſe at the object, is called the angle of the parallax. 4. The baſe is to the leſſer of the two diſtances of the object from the extremities of the baſe, as the tangent of the angle of parallax to radius; and to the greater, as the ſine of the ſame angle to radius.

Suppoſe lines to be drawn from the two ſtations to an object: one of the angles contained by theſe lines (as in the figure) being a right angle, the other will be the complement of the parallax to 90 degrees.

If the angles at the ſtations terminating a given baſe be known, it is eaſy, by trigonometry, to determine the diſtance of the object. N. B. We here ſuppoſe one of the angles at the baſe to be 90 degrees.

When the diſtance of an object is greater than 100,000 times the baſe, the angles at the two ſtations will not ſenſibly differ from two right ones; and conſequently the lines drawn from the object

object to the ſtations, are, phyſically ſpeaking, *parallel*.

Now the angle, whoſe tangent is to radius, as 1 to 100,000, is 2006, or very little more than a ſecond; and the moſt accurate inſtruments conſtructed for the menſuration of angles cannot be depended upon to 2 ſeconds.

Therefore the parallax of an object, whoſe diſtance is above 100,000 times greater than that between the two ſtations of obſervation, is inſenſible.

We may therefore conclude, that if the parallax of an object (obſerved with an inſtrument ſufficiently exact to meaſure an angle of 2 ſeconds) be inſenſible, the diſtance of it from either ſtation cannot be leſs than 100,000 times the baſe, from the extremities of which it is obſerved.

But you are to obſerve, that although the diſtance of the object cannot be leſs than 100,000 times the baſe, it may be greater in any aſſignable ratio.

Lines drawn from any given point in a baſe, to an object, may be eſteemed in practice parallel, without ſenſible error, if the diſtance of the object is more than 100,000 times the baſe.

Having laid down theſe few general principles, we may now proceed to explain the parallaxes uſed by aſtronomers, which are principally thoſe which ariſe from conſidering the object as viewed from the center of the earth and ſun, from the ſurface and the center of the earth, and from theſe compounded.

The diameter of the earth is the longeſt ſtrait line we can accurately obtain, and is in general the baſe uſed for determining the diſtances of celeſtial objects by their parallaxes.

The change in the apparent place of a planet, or fixed ſtar, or any celeſtial body, ariſing from it's

it's being viewed on the ſurface, or from the center of the earth, is called it's *diurnal parallax.*

To explain the parallaxes with reſpect to the earth, I ſhall uſe the diagram, *fig.* 2, *pl.* 7, where H S W repreſents the earth; T it's center; O R G part of the moon's orbit; P r g a part of a planet's orbit; Z a A part of the ſtarry heavens; Z S a line which paſſes through the zenith.

Now it is plain from the inſpection of the diagram, that a planet P ſituated in the zenith line, always anſwers to the ſame point of the heaven, whether it be regarded from the center T, or from the point S on the ſurface; *ſo that a celeſtial body in the zenith has no parallax.*

If the planet, inſtead of being in the zenith, is in the horizontal line S A, perpendicular to the line Z S, it's diſtance T from the center of the earth is the ſame as it's diſtance T P. But the place of the planet ſeen from the center of the earth is at d, while it's place ſeen from S or the ſurface is at A; the difference between theſe two ſituations is their *parallax.*

Let us now compare theſe two points or ſituations with the point Z, where the planet is ſeen, when in the zenith of the obſerver. The angle Z S g formed by the vertical line S Z, and the line S A in which the planet appears, is the *apparent* diſtance of the planet from the zenith: but if you were at the center of the earth, the angle Z T g would ſhew the *true* diſtance from the zenith.

The apparent diſtance Z S g, is greater than the true diſtance Z T g, in the right angled triangle g T S. Geometry proves that the angle Z S g is equal the two angles S T g, S g T. It is therefore greater than the angle S T g, by the quantity S g T. Thus the apparent diſtance of the planet from the zenith, is greater than the true diſtance;

and

and the difference between these two angles S g T, is the parallactic angle, which is in this case called the *horizontal parallax*, the line S T being the base.

The *parallax* of a celestial body, is then the angle formed from the center of the body by two lines, one of which proceeds to the center of the earth, the other to it's surface; or it is the inclination of two lines which proceed the one from the center, the other from the surface of the earth, to unite in the center of the planet; or still in other words, it is the angle at which the semidiameter of the earth will appear, seen from the center of the planet.

The triangle T S g, is called the *parallactic triangle*; it is always situated vertically, because the line S T is a vertical line; thus the whole effect of parallax is made in a vertical circle; indeed, as the center of the earth is under your feet, that is the plane of all the *vertical* circles. Therefore, parallax is always reckoned on these circles, making them appear lower, but never to the right or left of a vertical circle; consequently the parallax does not change the azimuth of a planet.

I have hitherto only spoken of the parallax when the planet is in the horizon, that is, when Z S g is a right angle, and I have called this the *horizontal parallax*. If the planet is nearer the zenith, as at ♈, the parallactic angle becomes smaller, and is called the parallax of altitude. It is evident by the diagram, that the horizontal parallax is the greatest of all, and that as the planet rises above the horizon it gradually diminishes until it comes to the zenith, where it vanishes or becomes equal to nothing. Thus the parallax A G D of the object G, is greater than the parallax a R B of the same object when at R; but when it is at O in the zenith, there is no parallax.

The parallax of a planet is smaller in proportion

portion as it is more diſtant; for the nearer g is to S, the greater is the angle S g T; hence mathematicians prove, that when the altitudes are the ſame, the parallax of altitude is in the inverſe ratio of the diſtance.

The horizontal parallax of the moon, which is the greateſt of all the planets, does not exceed a degree.

The parallax of a planet increaſes alſo with it's apparent diameter; in fact, the further a planet is off, the leſs is it's apparent diameter, and the diameter diminiſhes like the parallax in an inverſe ratio of the diſtance; therefore the parallax is as the diameter. If the parallax was leſſened one half, the diameter would be one half leſs; and the ſame relation ſubſiſts, whatever be the diſtance. Thus the diameter of the moon is always $\frac{6}{11}$ of it's parallax, and the cube of this fraction $\frac{1}{46}$, marks it's ſize with reſpect to the earth.

When the horizontal parallax of a celeſtial object is known, it is eaſy to diſcover, by the rules of trigonometry, the diſtance of the object; for in the right angled triangle S T G, you have the ſemi-diameter of the earth S T known, the angle S T D 90 degrees, and the parallactic angle T G S given, from whence it is eaſy to obtain the reſt. It is indeed difficult to determine the horizontal parallax with accuracy, on account of the effects of refraction. But the parallax of an object at any altitude being obſerved, it's horizontal parallax may be computed.

The diurnal parallax of an object according to the different ſituation of the ecliptic and equator in reſpect to the zenith, will ſometimes cauſe an apparent change or parallax of the latitude, longitude, declination, and right aſcenſion thereof.

In finding the *parallax of the ſun*, or which is the ſame, the angle under which the earth's ſemi-diameter would appear at that diſtance, the angle

is

is ſo exceeding ſmall, that a miſtake of one ſecond would occaſion an error of about ſeven millions of miles, from whence you may judge the exactneſs neceſſary in finding the parallax of any celeſtial object.

The *annual parallax* is the change in the apparent place of an object, which is cauſed by it's being viewed from the earth in different parts of it's orbit.

The annual parallax of all the planets is very conſiderable, that of the fixed ſtars inſenſible.

The ſun's parallax being ſo ſmall as to be ſcarcely ſenſible to the beſt obſervers when uſing the moſt accurate inſtruments, various indirect methods have been propoſed: of theſe, that ſuggeſted by Dr. Halley is allowed to be the moſt perfect. It was to obſerve the *tranſit* or paſſage of Venus over the ſun's diſc; a phenomenon which happened in the years 1761 and 1769, and by which this difficult problem was reſolved with an accuracy unlooked for by aſtronomers of ancient times.

OF THE APPARENT MOTION OF THE FIXED STARS, OCCASIONED BY THE ABERRATION OF LIGHT.

The aſtronomers of the laſt century, in their endeavours to diſcover the parallax of the fixed ſtars, found annual variations in the ſtars, following a law contrary to what would have happened, had it ariſen merely from the earth's ſituation in his orbit.

Theſe variations threw them into great perplexity, from which they were not relieved till Dr. Bradley, by applying himſelf to obſerve accurately theſe variations, at laſt diſcovered the true cauſe thereof; and has given rules for calculating the changes, and ſhewn what allowances are to be made in conſequence thereof, in obſervations of the ſtars.

 He

He has alſo proved clearly, that this aberration of the fixed ſtars, or the motion which makes them appear to deſcribe ellipſes of 40 ſeconds diameter, ariſes from *the motion of light* combined with *the annual motion of the earth.*

This I ſhall now endeavour to explain, and place in as clear a point of view as poſſible, deſiring you only to recollect the idea of decompoſition of forces into parallelograms, as explained in our Lectures on Mechanics. Let E, *fig.* 1, *pl.* 15, be a ſtar darting a ray of light, which I ſhall conſider here as a ſingle particle going from E to B. Let A B be a ſmall portion of the earth's orbit, of 20 ſeconds, for example; and C B the ſpace that the ray of light has paſſed through, while the earth moved from A to B; thus the particle was at C when the earth was at A, and arrives at B the ſame time as the earth. Hence C B and A B expreſs the velocity of light and the earth during 20 ſeconds.

Draw C D parallel to A B, and finiſh the parallelogram D B A; now according to the known principle of the compoſition and decompoſition of forces, we may conſider the velocity E B of the light, as reſulting from the two velocities in the directions C D, C A; the velocity C D being the ſame in quantity and direction as the velocity A D of the earth, cannot be perceived, is therefore deſtroyed with reſpect to us; the eye cannot ſee by a ray moving in the ſame direction and with the ſame velocity as the eye. So that only the part C A of the velocity of the light will ſubſiſt to us, and the ray will come to the eye in the direction C A, and we ſhall perceive the ſtar in the line A C, or according to B D which is parallel thereto; the angle C B D is what is termed the *aberration;* it is the quantity that a ſtar appears out of it's true place, in conſequence of the motion of light and the earth.

Perhaps

Perhaps another way of confidering this may render it more clear to your apprehenfions. Suppofe a tube to be erected perpendicular to the horizon at a time when it rains, the drops to fall in a perpendicular direction, and the tube to be of fuch a diameter as to admit but one drop at a time; now it is plain that if a drop of water enter the orifice of the tube, it will fall down without touching the fides. But if the tube be moved along, ftill preferving it's perpendicular direction, any drop that enters the tube will ftrike againft the fides, and none could pafs freely through while the tube is in motion, unlefs the tube has fuch a direction as will compenfate the motion.

Thus let A B, *fig.* 2, *pl.* 15, reprefent the horizon, C D the perpendicular tube, and G D the courfe of a drop of rain; then if C D be moved towards A, while the drop is falling within the tube, it is evident that the inner furface of the tube, which is fituated towards B, will be carried againft the drop, and prevent it's arriving at the bottom without touching. But if the inclined tube be moved with a fimilar motion to that of the drop from E to D, in the fame time that the drop moves from C to D, the lower orifice of the tube and the drop will be found at the fame inftant at D, and the velocity of the drop will be expreffed by C D, and that of the tube by E D.

The fame reafoning holds good, if inftead of drops of rain we fuppofe particles of light, and a telefcope inftead of a tube. For to an obferver, who through the tube C D views the vaftly diftant object C, if the motion of light be inftantaneous or infinitely fwift, no finite motion of C D, it's pofition being unaltered, can prevent it's being vifible; becaufe by the fuppofition the light which enters at C, will arrive at D before C D can have moved at all.

But if light be propagated in time, and the

obſerver be carried by a motion ſimilar as to acceleration to that of light, the tube muſt be inclined in an angle, whoſe ſine is to the ſine of C E D, as the velocity of the obſerver is to the velocity of light.

By this theory, which is eſtabliſhed by numerous obſervations of ſtars of different magnitudes and ſituations, it appears, that the ſmall apparent motion which the fixed ſtars have about their real places, which is called their aberration, ariſes from the proportion which the velocity of the earth's motion in her orbit bears to that of light.

This proportion is found to be as 10210 to 1; from whence it follows, that light moves or is propagated from the ſun to the earth, in 8 ſeconds, 12 thirds.

This diſcovery of the aberration of light by Dr. Bradley, is a direct proof of the motion of the earth in it's orbit. The motion of light, combined with the motion of the earth, produces an apparent difference in the places of the fixed ſtars; and as this motion is found to affect all the ſtars differently, according to their ſituations, it fully proves the truth of the cauſe upon which they were ſuppoſed to depend, and ſhews that the Copernican ſyſtem is conformable to nature and the order of things.

OF THE PRECESSION OF THE EQUINOXES.

The ſtars, which compoſe the conſtellations, are found to increaſe their longitude continually. The whole ſtarry firmament appears to have a ſlow motion, from weſt to eaſt, about the poles of the ecliptic, ſo that the conſtellations ſeem to have deſerted the places firſt appropriated to them; inſomuch that the firſt ſtar in the conſtellation of Aries, which appeared in the vernal interſection of the equator and ecliptic in the time of *Meton*, the

the Athenian, upwards of 1900 years ago, is now removed above 30 degrees from that point; so that Aries is now where Taurus was, Taurus where Gemini was, &c. The diſcovery of this motion is due to *Hipparchus* of Rhodes, one of the moſt celebrated aſtronomers of ancient times.

Hence the conſtellations on the zodiac of a celeſtial globe, do not agree in *figure* and *character*, the ſigns or conſtellations of the zodiac being to the eaſt of thoſe ſigns, or arcs of the ecliptic, which are called by the ſame names: for in order to avoid confuſion, aſtronomers thought proper to let the ſeveral portions of the ecliptic, where thoſe conſtellations were firſt obſerved to be, retain their old names, conſequently the vernal equinox is ſtill conſidered as the firſt point of Aries.

The ſpaces formerly occupied by the zodiacal conſtellations, retaining their ancient names, are called *anaſtra*, or *without their former ſtars*; whereas the ſpaces they now poſſeſs are called *ſtellata*.

This ſlow motion of the ſtars *forward*, is really cauſed by a like ſlow motion of the equinoctial points backwards; and this is owing to the revolution of the axis of the equator about the axis of the ecliptic; the pole of the equator deſcribing in the heavens a circle about the pole of the ecliptic.

By this preceſſion of the equinoctial points from eaſt to weſt, they meet the ſun every year 50 ſeconds of longitude before a complete revolution has been made. The time, in which the ſun appears to revolve from tropic to tropic, is called a *tropical year;* this with the time he has yet further to go to complete the revolution, namely, 50 ſeconds, is called the *ſiderial year*. Sir Iſaac Newton attributes this motion to the ſpheroidal figure of the earth, deducing from this

figure the revolution of the poles of the world round those of the ecliptic.

This motion carries the stars about 1 degree, 20 minutes, 23 seconds, in 100 years; so that the total revolution of the fixed stars eastward, back to the equinoctial points again, will be completed in 25972 years.

LECTURE

LECTURE XLII.

OF SOLAR AND SIDERIAL DAYS, OF MEAN TIME, THE EQUATION OF TIME, &c.

THE rotation of the earth about it's axis being uniform, it neceſſarily follows, that the apparent diurnal revolution of the ſtars about the earth muſt be alſo uniform, that is, made in equal times; they therefore will form a very proper meaſure to denote time. But then as they turn ſucceſſively with a conſtant motion, *one* muſt be ſelected, by whoſe revolutions time may be meaſured; we muſt alſo fix a term from whence to commence our reckoning.

The *ſun* being the moſt conſpicuous object, was fixed upon by the aſtronomers of early ages, as the moſt proper meaſure for the parts of time. But when more accurate obſervations were made, the ſun's motion was found not to be uniform, and conſequently the time meaſured thereby would be neither regular nor equal; they were therefore obliged to find out a mean or regular time for the baſis of their calculations.

An aſtronomical or ſolar day is divided into 24 hours, reckoning them in numeral ſucceſſion, from 1 to 24. The firſt twelve hours are ſometimes diſtinguiſhed by the mark P M for afternoon, the other twelve are diſtinguiſhed by A M for before noon. Aſtronomers generally reckon through the 24 hours from noon to noon; and what is by the common way of reckonig called morning

hours, is by them reckoned in ſucceſſion from noon to midnight. Thus 5 o'clock in the morning of April the 10th, is by aſtronomers called April 9, 17 hours.

If the ſun had no other apparent motion but that of it's *diurnal* revolution, it would every day deſcribe the ſame parallel, and be accompanied by the ſame ſtars. But it has alſo an apparent *annual* motion, by which it ſeems to be carried through the zodiac every year, from weſt to eaſt, that is, in a direction contrary to that of it's diurnal revolution.

Hence, if on any day the ſun and a ſtar paſs the meridian at the ſame inſtant, on the next day when the ſtar returns to the meridian, the ſun will have departed towards the weſt, as much ſpace as in that interval it has paſſed over by it's annual motion, and will therefore arrive at the meridian ſome moments after the ſtar; the day following it will be ſtill later, ſo that at the end of ſix months, it paſſes 12 hours after the ſtar, which has therefore gained 12 hours on the ſun; and at the end of the year, the ſtar will have paſſed 366 times over the meridian, where the ſun has only paſſed 365 times.

In this view we have conſidered the ſun's apparent motion; the reſult is the ſame, if you conſider the earth's real motion. If indeed the earth had *no real* motion, and conſequently the ſun *no apparent* motion, the length of a natural day would be about 23 hours 56 minutes, for in that time a revolution of the earth is completed, as appears by an eaſy obſervation; for any fixed ſtar that is on the meridian at a given hour of night, will after 23 hours 56 minutes, be on the meridian again the night following. This interval of time is called a *ſiderial* day.

Thus

Thus you fee that there is a diftinction between a *folar day* and a *fiderial day*.

A folar or aftronomical day is the fpace of time that intervenes between the fun's departing from any one meridian, and it's return to the fame again. The *fiderial day* is the fpace of time that elapfes between the departure of a ftar from a given meridian, and it's return to the fame again.

I fhall now endeavour to fhew you, why thefe days differ in length; that is, why the fun takes up more time to complete one revolution than a ftar.

This difference arifes from the fun's annual motion. The fun does not continue always in the fame place in the heaven, as the fixed ftars do: but if it is feen at M, *fig.* 2, *pl.* 4, one day, near the fixed ftar R, it will have fhifted it's place the next day, and will be near to fome other fixed ftar L. This motion of the fun is from weft to eaft, and one entire revolution is completed in a year. Suppofe, therefore, that the fun, when it is at M, near to the fixed ftar R, appears in the fouth of any particular place S; and then imagine the earth to turn once round upon it's axis from weft to eaft, or in the direction S T V W, fo that the place may be returned to the fame fituation; after this rotation is completed, the ftar R will be in the fouth of the place as before; but the fun having, in the mean time, moved eaftwards, and being near to the ftar L, or to the eaft of R, will not be in the fouth of the place S, but to the eaftward of it: upon this account, the place S muft move on a little farther, and muft come to T before it will be even with the fun again, or before the fun will appear exactly in the fouth.

This may be illuftrated by an inftance. The two hands of a watch are clofe together, or even with

with one another at twelve; they both turn round the ſame way, but the minute hand turns round in a ſhorter time than the hour hand; when the minute hand has completed one rotation, and is come round to twelve, the hour hand will be before it, or will be at one; ſo that the minute hand muſt move more than once round, in order to overtake the hour hand, and be even with it again.

As this ſubject is of ſome importance, we ſhall endeavour to render it more clear, by placing it in a different point of view.

The diameter of the earth's orbit is but a phyſical point, in proportion to the diſtance of the ſtars; for which reaſon, and the earth's uniform motion on it's axis, any given meridian will revolve from any ſtar to the ſame ſtar again, in every abſolute turn of the earth upon it's axis, without the leaſt perceptible difference of time being ſhewn by a clock which goes exactly true.

If the earth had only a diurnal, without an annual motion, any given meridian would revolve from the ſun to the ſun again, in the ſame quantity of time as from any ſtar to the ſame ſtar again; becauſe the ſun would never change his place, with reſpect to the ſtars. But as the earth advances almoſt a degree eaſtward in it's orbit, in the time that it turns eaſtward round it's axis, whatever ſtar paſſes over the meridian on any day with the ſun, will paſs over the ſame meridian on the next day, when the ſun is almoſt a degree ſhort of it, that is, 3 min. 56 ſeconds ſooner. If the year contained only 360 days, the ſun's apparent place, ſo far as his motion is equable, would change a degree every day, and then the ſiderial days would be juſt four minutes ſhorter than the ſolar.

Let A B C D E F G H, *fig.* 3, *pl.* 4, be the earth's

earth's orbit, in which it goes round the ſun every year, according to the order of the letters, that is, from weſt to eaſt, and turns round it's axis the ſame way, from the ſun to the ſun again, in every twenty-four hours. Let S be the ſun, and R a fixed ſtar, at ſuch an immenſe diſtance, that the diameter G C of the earth's orbit bears no ſenſible proportion to that diſtance; N m n the earth in different points of it's orbit. Let N m be any particular meridian of the earth, and N, a given point, or place, lying under that meridian.

When the earth is at A, the ſun S hides the ſtar R, which would always be hid if the earth never moved from A; and conſequently as the earth turns round it's axis, the point N would always come round to the ſun and the ſtar at the ſame time.

But when the earth has advanced through an eighth part of it's orbit, or from A to B, it's motion round it's axis will bring the point N an eighth part of a day, or three hours, ſooner to the ſtar than to the ſun. For the ſtar will come to the meridian in the ſame time as though the earth had continued in it's former ſituation at A, but the point N muſt revolve from N to n, before it can have the ſun upon it's meridian. The arc N n being therefore the ſame part of a whole circle, as the arc A B, it is plain that any ſtar which comes to the meridian at noon, with the ſun, when the earth is at A, will come to it at nine o'clock in the forenoon, when the earth is at B.

When the earth has paſſed from A to C, one-fourth part of it's orbit, the point N will have the ſtar upon it's meridian, or at ſix in the morning, ſix hours ſooner than it comes round to the ſun; but the point N muſt revolve ſix hours more, before it has mid-day by the ſun: for now the angle A S S is a right angle, and ſo is N C n; that is, the

the earth has advanced 90 degrees on it's axis, to carry the point N from the ſtar to the ſun; for the ſtar always comes to the meridian when N m is parallel to R S A; becauſe D S is but a point in reſpect to R S. When the earth is at D, the ſtar comes to the meridian at three in the morning, at E, the earth having gone half round it's orbit; N points to the ſtar at midnight, it being then directly oppoſite to the ſun; and, therefore, by the earth's diurnal motion, the ſtar comes to the meridian twelve hours before the ſun, and then goes on, till at A it comes to the meridian with the ſun again.

Thus it is plain, that one abſolute revolution of the earth on it's axis (which is always completed when any particular ſtar comes to be parallel to it's ſituation at any time of the day before) never brings the ſame meridian round from the ſun to the ſun again; but that the earth requires as much more than one turn on it's axis, to finiſh a natural day, as it has gone forward in that time, which, at a mean ſtate, is a 365th part of a circle, that is, 59 minutes, 8 ſeconds; for as 365 days are to 1 day, ſo are 360 degrees to 59 minutes 8 ſeconds. Hence, in 365 days the earth turns 366 times round it's axis, and conſequently, as one revolution of the earth on it's axis completes a ſiderial day, there muſt be one more ſiderial day in a year than there are ſolar days.

OF MEAN AND APPARENT TIME.

Further and more accurate obſervations ſhewed, that the ſolar days were not equal to each other; after inveſtigating this ſubject, aſtronomers were under the neceſſity of diſtinguiſhing two ſorts of time, one they called *true and apparent time*, the other *mean time*.

True

True and apparent time is determined by the interval between the ſun's center paſſing the meridian, and that of his next return to the ſame meridian. It is that ſhewn by a *ſun-dial*, which marks the hours every day in ſuch a manner, that every hour is a 24th part of the time, between the noon of that day, and the noon of the day immediately following.

Mean time is that ſhewn by a clock, which goes uniformly.

The time ſhewn by a ſun-dial, and the mean time, or that ſhewn by a well regulated clock, agree only four times in the year, on the 15th of April, the 16th of June, the 31ſt of Auguſt, and the 24th of December.

The *clock*, if it goes equably and true all the year round, will be *before* the ſun from the 24th of December to the 15th of April; from that time to the 16th of June, the *ſun* will be *before* the clock; from thence to the 31ſt of Auguſt, the clock will be again before the ſun, and from the 31ſt of Auguſt to the 24th of December, the ſun will be faſter than the clock. On any other day, if you would ſet a clock by a ſun-dial, you muſt make uſe of an *equation table*, which ſhews, for every day in the year, how many minutes or ſeconds the ſun is before or behind the clock; the difference between the ſun and the clock is called the *equation of time*.

Both the ſolar and mean day are divided into 24 hours, or 86400 ſeconds.

Three hundred and ſixty degrees of the equator paſs under the meridian in a mean day more 59 minutes, 8 ſeconds, which is that part of 360 degrees of the ſun's annual motion correſponding to the time of a mean day.

In a ſolar or true day, the 360 degrees of the equator paſs under the meridian more an arc thereof

thereof anſwering to the ecliptic arc deſcribed the ſame day, called the ſun's motion in right aſcenſion.

When the ſun is furtheſt from the earth, or in apogee, his motion in right aſcenſion in a day, is 1 degree, 2 minutes, 6 ſeconds; therefore 361 degrees, 2 minutes, 6 ſeconds, paſs the meridian in a ſolar day. By working this proportion, as 360 degrees, 59 minutes, 8 ſeconds, is to 24 hours, ſo is 361 degrees, 2 minutes, 6 ſeconds, we find 24 degrees, 0 minutes, 12 ſeconds. Conſequently when the ſun is in apogee, the ſolar day is 12 ſeconds longer than the mean day.—From hence it follows:

1. That in every ſecond of a clock well regulated to mean time, an arc of 15 minutes 28 ſeconds of the equator paſſes the meridian; for this is the quotient of 360 degrees, 59 minutes, 8 ſeconds, divided by 86400 ſeconds.

2. That a ſtar's revolution anſwers to 360 degrees of the equator, while the mean day anſwers to 360 degrees, 59 minutes, 8 ſeconds. This difference of 59 minutes, 8 ſeconds, being reduced to time, gives 3 minutes, 56 ſeconds. Therefore the ſtars anticipate 3 minutes, 56 ſeconds, every day on mean time; or, which is the ſame, a ſtar's diurnal revolution is made in 23 hours, 56 minutes, 4 ſeconds.

3. To find whether a clock be well regulated to mean time, obſerve if it ſhew exactly 23 hours, 56 minutes, 4 ſeconds, from the inſtant of any ſtar's paſſage through a fixed point, to that of it's return to the ſame point. By what the clock exceeds this, it is faſter, by what it wants thereof, it is ſlower than mean time.

OF THE EQUATION OF TIME.

I have already obſerved to you, that the *equation*

tion of time is the difference between mean and apparent time, or that pointed out by a good clock and a fun-dial.

You will foon perceive, that there would have been no difference, and confequently no need for any equation, 1ft, if the earth's orbit was a perfect circle with the fun at the center; 2dly, if the earth had moved through an equal part or portion of that circle every day; and 3dly, if the axis of her diurnal motion was always perpendicular to the plane of her orbit. But neither of the foregoing fuppofitions is true; for, 1. the orbit of the earth is an *ellipfe;* 2. her motion therein is not equal; and 3. her axis is inclined to the plane of her orbit: the meafure of time therefore, as far as it depends on thefe circumftances, muft be *unequal,* and fubject to an *equation.*

The equation of time may then be confidered as arifing, 1. from the obliquity of the ecliptic to the equator; 2. from the unequal progreffion of the earth through her elliptic orbit.

Of the firft caufe of inequality, or that arifing from the obliquity of the earth to the ecliptic.

The motion of the earth on it's axis is perfectly equable, or always at the fame rate; and the plane of the *equator* being perpendicular to it's axis, it is evident, that in equal times, *equal portions* of the *equator* would pafs over the meridian; and fo alfo would equal portions of the *ecliptic,* if it were either parallel to, or coincident with the equator.

But as the ecliptic is *oblique* to the equator, the *equable* motion of the earth carries *unequal portions* of the *ecliptic* over the meridian in equal times, the difference being proportionate to the obliquity; and as fome parts of the ecliptic are more oblique than others, thofe differences are unequal among themfelves. If, therefore, we fhould

fuppofe

ſuppoſe two ſuns to ſtart from the beginning either of Aries or Libra, and continue to move through equal arcs in equal times, one in the equator, the other in the ecliptic, the equatorial ſun would always return to the meridian in 24 hours time as meaſured by a good clock, but the ſun in the ecliptic would return to the meridian ſometimes ſooner, ſometimes later, than the equatorial ſun, and only the ſame inſtant with him four days in the year.

To render this plainer, we will have recourſe to a diagram, *fig.* 4, *pl.* 4. This figure is to be conſidered as a view of part of the concave ſphere of the heaven, wherein D E repreſents a part of the celeſtial equator, F G a part of the ecliptic, A the interſection of the two circles at the *vernal equinox*, A B a degree upon the equator. If we imagine the plane of the meridian to paſs from the ſituation M M, into the ſituation N N, in going through the arc A B, one degree of the equator, it will alſo go through the arc A C more than one degree of the ecliptic. For in the triangle A B C, the angle at B is a right one, conſequently the hypothenuſe A C is the longeſt ſide.

At the *ſolſtices* the obliquity of the ecliptic has a contrary effect, and helps to lengthen the natural days: this will be eaſily comprehended by viewing the dragram, *fig.* 5, *pl.* 4, where T T is part of the tropic of Capricorn, C D part of the ecliptic, which may be conſidered as coincident with the tropic for ſome diſtance on each ſide of the ſolſtitial point, as from A to B; and therefore meridians, which are perpendicular to the tropics, may be conſidered for that ſpace as perpendicular to the ecliptic. This being ſuppoſed, a meridian, in going from A towards B, will go through as large an arc in the tropic as the ecliptic: but the tropic not being a great circle, any arc

arc, as a b, taken in both these circles, will measure more minutes in the tropic than in the ecliptic, and that in the ratio as the ecliptic exceeds the tropic in dimensions: now the circumference of the ecliptic is to that of the tropic, nearly as 60 to 55; and therefore the arc a b, of 55 minutes in the ecliptic, will be 60 minutes in the tropic. But every meridian passes in the same time through similar arcs in the celestial equator, and all circles parallel to the equator, as the tropic's arc: consequently at the solstices every arc of the ecliptic passed through by any meridian in a given time, will be to the arc of the equator passed through in the same time, as 55 to 60.

The second cause of the difference in the time shewn by a well regulated clock, and a true sundial, arises from the inequality of the sun's apparent motion, which is *slowest* in *summer*, when the sun is *farthest* from the earth, and *swiftest* in the *winter*, when he is nearest thereto; whereas the earth's motion on it's axis is equable all the year round.

If the sun's apparent motion in the ecliptic were equable, the whole difference between the equal time as shewn by the clock, and the unequal time as shewn by the sun, would arise from the obliquity of the ecliptic. But this is not the case, for the sun's motion sometimes exceeds *a degree* in 24 hours, though it is generally less. And when his motion is slowest, any particular meridian will return and revolve sooner to him than when his motion is quickest, for it will overtake him in less time when he advances through a less space, than when he moves through a larger.

On the first of January, the daily motion of the sun in the ecliptic is nearly 1 degree, 1 minute, 13 seconds; but on the first of July, the daily motion is 57 minutes, 13 seconds; the medium of these is 59 minutes, 13 seconds. The sun's place in the

ecliptic

ecliptic, calculated on the ſuppoſition of a daily motion of 59 minutes, 13 ſeconds, will be behind his obſerved place from the beginning of January to the beginning of July, and will be before it from the beginning of July to the beginning of January; the greateſt difference is about 1 degree, 55 minutes, 32 ſeconds, which is obſerved about the beginning of April and October, at which time the obſerved daily motion is 59 minutes, 13 ſeconds.

It is neceſſary for an aſtronomer to know both true and mean time; the firſt, to aſcertain the time of obſervation; the ſecond, becauſe the tables of the planets, &c. are calculated in conformity thereto.

The relation between true and mean time, is diſcovered by obſerving the time marked by your clock, at the inſtant when the center of the ſun paſſes the meridian, and adding what it wants of 12 hours, or ſubtracting the exceſs above it.

It is obtained for any other hour beſides 12, by taking from the difference between the time it has paſſed on two ſubſequent days, the part proportional to the hour you are ſeeking.

Example: March 3, when the ſun's center paſſed the meridian, the clock was 12 hours, 17 minutes, 49 ſeconds; the clock was therefore 17 minutes, 49 ſeconds, faſter than true or apparent time.

On the 4th of March, it was 12 hours, 17 minutes, 42½ ſeconds; the difference is 6½ ſeconds, or about ¼ of a ſecond per hour. Now on the 3rd, the planet Mars paſſed the meridian at 14 hours, 27 minutes, 32 ſeconds; the pendulum was 3½ ſeconds more advanced than at noon, which gives it's advance for that hour, 17 minutes, 45½ ſeconds, which ſubtracted from 14 hours, 27 minutes, 32 ſeconds, gives 14 hours, 9 minutes, 46½ ſeconds, for the true or apparent time of the tranſit of Mars.

From

From what I have now explained to you, it appears that there is no body in nature, whofe motion is perfectly uniform and regular; that whenever we look for *commenfurabilities* and *equalities* in nature, we are always difappointed. The earth is fpherical, but not perfectly fo; the fummer is unequal when compared with the winter; the ecliptic difagrees with the equator, and never cuts it twice in the fame equinoctial point; the orbit of the earth has an eccentricity, more than double in proportion to the fpheroidity of it's globe; no number of the revolutions of the moon coincide with any number of the revolutions of the earth in it's orbit; no two of the planets meafure one another; and thus it is wherever we turn our thoughts, fo different are the views of the CREATOR from our narrow conception of things; where we look for *commenfuration*, we find *variety* and *infinity*.*

It is fcarce poffible to refrain here from joining with an elegant moralift in obferving, that all the appearances of nature uniformly confpire to remind us of the lapfe of time, and the flux of life. The day and night fucceed each other, the rotation of the feafons diverfifies the year, the fun attains the meridian, declines and fets, and the moon every night changes it's form.

The day may be confidered as an image of the year, and a year as the reprefentation of life. The morning anfwers to the fpring, and the fpring to childhood and youth; the noon correfponds to the fummer, and the fummer to the ftrength of man hood; the evening is an emblem of autumn, and autumn of declining life. The night, with it's filence and darknefs, fhews the winter, in which all the powers of vegetation are benumbed; and the

* Jones's Phyfiological Difquifitions.

winter points out the time when life ſhall ceaſe, with it's hopes and pleaſures.

He that is carried forward, however ſwiftly, by a motion equable and eaſy, perceives not the change of place, but by the variation of objects. If the wheel of life, which rolls thus ſilently along, paſſed on through undiſtinguiſhable uniformity, we ſhould never mark it's approaches to the end of the courſe. If one hour were like another; if the paſſages of the ſun did not ſhew it's waſting; if the change of ſeaſons did not impreſs upon us the flight of the year; quantities of duration, equal to days and years, would glide away unobſerved. If the parts of time were not variouſly coloured, we ſhould never diſcern their departure or ſucceſſion; but ſhould live thoughtleſs of the paſt, and careleſs of the future, without will, and perhaps without power, to compare the time which is already loſt, with that which may probably remain.

LECTURE

LECTURE XLIII.

On the Planetarium, Tellurian, and Lunarium.

TO repreſent by machines the motions and various aſpects of the heavenly bodies, the parallelifm of the earth's axis, together with it's annual and diurnal motions, and by this means to explain the beautiful variety of ſeaſons and other terreſtrial and celeſtial phenomena, has ever been conſidered as one of the nobleſt efforts of mechanical genius. Among the variety of machines contrived for theſe purpoſes, that before you (*fig.* 1, *pl.* 11,) is the beſt adapted for repreſenting the celeſtial motions.

It ſeems highly probable, that the ancients were not unacquainted with planetary machines, but that the ſame powers of genius which led them to contemplate and reaſon upon the heavenly bodies, induced them to realize their ideas, and form inſtruments for explaining them; and we may fairly preſume, theſe were carried to no ſmall degree of perfection, when we conſider that of one *Archimedes* was the maker, and *Cicero* the encomieſt.

A planetarium may be conſidered in ſome ſort as a diametrical ſection of our univerſe, in which the upper and lower hemiſpheres are ſuppreſſed.

The upper plate is to anſwer for the *ecliptic*; on this are placed, in two oppoſite, but correſponding circles, the days of the month, and the

 ſigns

ſigns of the ecliptic, with their reſpective characters; by this plate you may ſet the planetary balls ſo as to be in their reſpective places in the ecliptic, for any day in the year.

Through the center of this plate, you obſerve a ſtrong ſtem, on which is a braſs ball to repreſent the *ſun;* round the ſtem are different ſockets to carry the arms, by which the ſeveral planets are ſupported. The planets are repreſented by ivory balls, having the hemiſphere which is next the ſun white, the other black, to exhibit their reſpective phaſes. I can with eaſe either take off, or put on, any of the planets, as occaſion may require. About the primary planets are placed the ſecondary planets or moons, which are in this inſtrument only moveable by the hand.

I turn the handle, and all the planets are put in motion, moving round that ball which repreſents the ſun. Now if you take the earth's motion as a ſtandard, they move with the ſame relative velocities and periodical times that they have in the heavens. I ſcarcely need obſerve, that it is impoſſible to give an idea of the proportion and diſtances of the planets in the compaſs of an inſtrument ſo ſmall as that before you, or indeed of any inſtrument whatſoever.

The motions are carried on by a train of wheel-work concealed in the box under the ecliptic.

GENERAL EXPLANATION OF THE SOLAR SYSTEM, BY THE PLANETARIUM.

As the center of the ſolar ſyſtem is the only place from which the motion of the planets can be truly ſeen, let us ſuppoſe ourſelves ſituated at the center of the ball repreſenting the ſun. In this ſituation the heavens would appear perfectly ſpherical,

cal, the ſtars being ſo many lucid points in the concave ſurface of the ſphere.

Having attentively conſidered the ſtars for a long time, you will remark two ſorts, the one ſcattered throughout the heavens unequally luminous, perfectly at reſt, and therefore called *fixed ſtars*; the other ſort moving round the ſun with unequal velocities, called *planets*. By taking one of the fixed ſtars for a point to ſet out from, or for this purpoſe in our inſtrument, uſing any of the points into which the ecliptic is divided, it will be eaſy to determine the motions of the planets.

Thus by obſerving the earth as I turn the winch, you may perceive that it continually approaches nearer and nearer to the more eaſtern ſigns; in a certain ſpace of time, it will return to the place from whence it ſet out.

Thus you ſee how readily the periods of the planets revolutions may be obtained, by obſerving the time that elapſes between their ſetting out from any fixed point, and returning to the ſame again. The annual motion of the earth is the baſis or ſtandard, to which the motions of the other planets are compared; and this is one of the reaſons, why the months and days of our months are engraved on the ecliptic circle of the planetarium.

The curves which the planets deſcribe in their revolutions, are what are called their *orbits*.

If the paths of the planets were in one place, as in this inſtrument, they would all be referred to one circle in the heavens; but this is not the caſe, for their paths croſs each other in different parts of the heavens.

When you conſider the motions of the little ſyſtem before you, while you are ſuppoſed to view it from the ſun, all is regular; but when you view it from the earth, many of the appearances become

intricate and perplexed. When the works of GOD are examined from a proper point, there is nothing but *uniformity*, *beauty*, and *precision*, and the heavens present you with a plan inexpressibly magnificent, and yet regular beyond the power of invention. When properly examined and looked into, you will always find the volume of the universe as perfect as it's author, containing mines of truth for ever opening, fountains of good for ever flowing, being an endless succession of brighter and still brighter exhibitions of the glorious godhead, always answering the nature and idea of infinite fulness and perfection.

In the center of the system is the *sun*, placed in the heavens by that *Almighty Power* who said, "Let there be light, and there was light," to be the fountain of light and heat to all the planets revolving round him. In this machine, his situation is pointed out by this brass ball.

The nearest planet to the sun is *Mercury*; observe the part of the ecliptic he is at, and also the place where the earth is situated. I now turn the handle, Mercury is arrived at the place from whence he set out, and our earth has gone over 88 days of the ecliptic; the velocity we here give the planet is inconsiderable, but in his course in the heavens he is supposed to move with a velocity equal to 100,000 miles in an hour.

Venus is the next planet in the system; in the heavens she is distinguished by the superiority of her lustre, appearing to us the brightest and largest of all the planets. By observing her course through the ecliptic, and comparing it with the days passed over by the earth at the same time, you will find in our instrument, Venus revolving round the sun in 225 days; in the heavens she moves at the rate of 80,955 miles in an hour.

The third planet in the solar system is the

Earth;

Earth; diminutive as it appears before you in this inſtrument, it's real diameter is near 8000 miles; it revolves round the ſun in the ſpace of 365 days, into which number the brazen ecliptic is divided; this revolution conſtitutes our year, while it's revolution round it's axis forms day and night.

The little ball cloſe and annexed to the earth, repreſents the *Moon*, of which I ſhall ſay nothing at preſent, as there is a part of the inſtrument for explaining more particularly her phenomena.

The planet *Mars* is next in order, being the firſt above the earth's orbit; he revolves round the ſun in about 686 days; ſo that our earth, as you will obſerve by the inſtrument, goes nearly twice round, while he is performing his revolution; he is ſuppoſed to move at the rate of 55,783 miles an hour. To this planet our earth and moon will appear like two moons, ſometimes half or three quarters illuminated, but never full.

Jupiter, the largeſt of all the planets, is next beyond Mars; and our earth muſt have gone nearly 12 times round the ecliptic for one revolution of Jupiter; yet ſo far is it's path removed from the ſun, that to go round it in this ſpace of time, it moves at the rate of 30,193 miles an hour. Though larger than the earth, it appears but ſmall in the heavens, becauſe, as you know, objects decreaſe in their *apparent* magnitude in proportion to their *real* diſtance. It is attended with 4 ſatellites, here repreſented by theſe 4 balls; they are inviſible to the naked eye, but appear beautiful through a teleſcope.

Saturn, the next planet, is ſtill higher in the ſyſtem, performing it's circuit in about thirty years of our time; ſo that in this inſtrument it's motion is ſcarcely ſenſible, while in the heavens it goes at the rate of 22,298 miles an hour. It is accompanied by five ſatellites, and a large luminous,

nous ring, here reprefented by this ivory circle, and which is one of the moft curious phenomena of nature.

The *Georgium Sidus*, or Georgian planet, fo called in compliment to his Majefty King George the III. (the Royal patron and promoter of the arts and fciences) is the feventh planet in our fyftem; it is near twice the diftance of Saturn from the fun, round which it revolves in about 80 years.

To explain, by the planetarium, why the fun, being a fixed body, appears to pafs through all the figns of the zodiac in twelve months, or one year. It will fhew that this phenomenon is occafioned by the annual motion of the earth.

As the general phenomena of the planetary fyftem will be the beft underftood by an induction of particulars, I fhall remove all the planets but thofe whofe motion I am going to explain; for inftance, I fhall leave only the earth and fun, and place the earth over *Libra*, and it is plain that the fun will then be transferred by the eye of a fpectator on the earth to *Aries*, in which fign it will appear at the latter end of March: move the earth on in it's orbit to Capricornus, and the fun will appear at Cancer in June, feeming to have moved from ♈ to ♋, though it has not ftirred, the real motion of the earth having caufed the fpectator to transfer the fun to all the intermediate points in the heavens, and thus given it an apparent motion. Continue to move the earth till it arrives at Aries, and the fun will be feen in Libra in the month of September: moving the earth on to Cancer, the vifual ray of the fpectator refers the fun to Capricorn, as it appears in the month of December. Laftly, continue moving the earth, and

and it will arrive at Aries, where we ſet out. Thus I have ſhewn, that it is the motion of the earth which cauſes the ſun to appear in all the different ſigns of the zodiac. Cuſtom, indeed, has taught us to ſay *the ſun is in Aries*, when it is between us and Aries, and ſo of any other ſign; whereas it would have been more proper to ſay, that the *earth is in Libra.*

To ſhew why at different times of the year we ſee the heavens decorated with an entire different collection of ſtars.

This phenomenon is occaſioned by the earth's progreſſive or annual motion: while the earth is traverſing it's courſe under the vaſt concave of fixed ſtars, we are gradually carried under the different conſtellations. From hence it is evident, that at night when the earth is turned from the ſun, we ſhall in ſucceſſion have the opportunity of viewing from time to time all the ſtars in the zodiac, and conſequently a different conſtellation will preſent itſelf every month.

Thus, the Pleiades are not viſible in the ſummer; but in the winter the earth is got between the ſun and them. Theſe ſtars are obſervable at night, becauſe they are not intercepted from our ſight by the ſun's rays; and in this manner they appear during the whole winter, only they ſeem to get more weſterly every night, as the earth moves gradually by them to the eaſt. To make this ſtill more clear, place the earth in the planetarium between the ſun and any of the ſigns, that ſide towards the ſun will be day, and that towards the ſign night: it follows, that at night we are turned towards the ſtars, which in that ſign (ſuppoſe, as before, the Pleiades in Taurus) will then be conſpicuous to us; but as the ſpring approaches, the earth

earth withdraws itſelf from between the ſun and the Pleiades, till at length the earth, by it's progreſſive motion, gets the ſun between it and the ſtars, which then lie hid behind the ſolar rays: after the ſame manner, while the earth performs it's annual tract, the ſun, which always ſeems to move the contrary way, darkens, by his ſplendor, the other conſtellations, ſucceſſively; but the ſtars oppoſite to thoſe hid by the ſun, are at night preſented to our view.

GENERAL PHENOMENA OF THE PLANETS.

I ſhall now place the earth, Mars, and Venus, on the planetarium, and as each planet moves with a different degree of velocity, they are continually changing their relative poſitions. Thus on turning the handle of the machine, you find, 1ſt, that the earth moves twice as faſt as Mars, making two revolutions while he makes one; and Venus, on the other hand, moves much faſter than the earth. Secondly, that in each revolution of the earth theſe planets continually change their relative poſitions, correſponding ſometimes with the ſame point of the ecliptic, but much oftener with different points.

To explain the conjunction, oppoſition, elongation, and other phenomena of the inferior planets.

We may now proceed to make ſome obſervations on the motions of Venus, as obſerved in the planetarium. If conſidered as viewed from the ſun, we ſhall find that Venus would appear at one time nearer to the earth than at another; that ſometimes ſhe would appear in the ſame part

of the heavens, and at others in oppofite parts thereof.

As the planets, when feen from the fun, change their pofition with refpect to the earth, fo do they alfo, when feen from the earth, change their pofition with refpect to the fun, being fometimes nearer to, at others farther from, and at times in conjunction with him.

But the conjunctions of Venus or Mercury, feen from the earth, not only happen when they are feen together from the fun, but alfo when they appear to be in oppofition to the folar fpectator. To illuftrate this, bring the earth and Venus to the firft point of Capricon; then by applying a ftring from the fun over Venus and the earth, you will find them to be in conjunction, or on the fame point of the ecliptic.

Whereas if you turn the handle till the fun is between Venus and the earth, a fpectator in the fun will fee Venus and the earth in oppofition; but an inhabitant of the earth will fee Venus not in oppofition to the fun, but in conjunction with him.

In the firft conjunction Venus is between the fun and earth; this is called the inferior conjunction. In the fecond, the fun is fituated between the earth and Venus; this is called the fuperior conjunction.

After either of thefe conjunctions, Venus will be feen to recede daily from the fun, but never departing beyond certain bounds, never appearing oppofite to the fun; and when fhe is feen at the greateft diftance from him, a line joining her center with the center of the earth, will be a tangent to the orbit of Venus.

To illuftrate this, I take off the fun from it's fupport, and the ball of Venus from it's fupporting ftem, and place this wire, (*fig.* 2, *pl.* 11,) fo that

that one part P may be on the ſtem that ſupports the earth, and a ſimilar ſocket (*fig.* 3,) on the pin which ſupports the ball of Venus; the wire (F) is to lie in a notch at the top of the ſocket, which has been put upon the ſupporting ſtem of Venus: then will the wire repreſent a viſual ray going from an inhabitant of the earth to Venus. By turning the handle, you will now find that the planet never departs further than certain limits from the ſun, which are called it's greateſt elongations, when the wire becomes a tangent to the orbit; after which, it approaches the ſun, till it arrives at either the inferior or ſuperior conjunction.

It is alſo evident from the inſtrument, that Venus, from her ſuperior conjunction, when ſhe is furtheſt from the earth, to the time of her inferior conjunction, when ſhe is neareſt, ſets later than the ſun, is ſeen after ſun-ſet, and is, as it were, the forerunner of night and darkneſs. But from the inferior conjunction, till ſhe comes to the ſuperior one, ſhe is always ſeen weſtward of the ſun, and muſt conſequently ſet before him in the evening, and riſe before him in the morning, foretelling that light and day are at hand.

Bring Venus and the earth to the beginning of Aries, when they will be in conjunction; and turn the handle for nearly 225 days, and as Venus moves faſter than the earth, ſhe will arrive at Aries, and have finiſhed her courſe, but will not have overtaken the earth, who has moved on in the mean time; and Venus muſt go on for ſome time, in order to overtake her. Therefore, if Venus ſhould be this day in conjunction with the ſun, in the inferior part of her orbit, ſhe will not come again to the ſame conjunction till after 1 year, 7 months, and 12 days.

It is plain, by inſpection of the planetarium, that

that though Venus does always keep nearly at the ſame diſtance from the ſun, yet ſhe is continually changing her diſtance from the earth; her diſtance is greateſt when ſhe is in her ſuperior, and leaſt when ſhe is in her inferior conjunction.

To explain the phaſes, the retrograde, direct, and ſtationary ſituations of the planets.

As Venus is an opake globe, and only ſhines by the light ſhe receives from the ſun, that face which is turned towards the ſun will always be bright, while the oppoſite one will be in darkneſs; conſequently, if the ſituation of the earth be ſuch, that the dark ſide of Venus be turned towards us, ſhe will then be inviſible, except ſhe appear like a ſpot on the diſk of the ſun. If her whole illuminated face is turned towards the earth, as it is in her ſuperior conjunction, ſhe appears of a circular form, and according to the different poſitions of the earth and Venus, ſhe will have different forms, and appear with different phaſes, undergoing the ſame changes of form as the moon. Theſe different phaſes are ſeen very plain in this inſtrument, as the ſide of the planet, which is oppoſite to the ſun, is blackened; ſo that in any poſition, a line drawn from the earth to the planet, will repreſent that part of her diſk which is viſible to us.

The irregularities in the apparent motions of the planets, is a ſubject that this inſtrument will fully elucidate; and the pupil will find that they are only apparent, taking their riſe from the ſituation and motion of the obſerver. To illuſtrate this, let us ſuppoſe the above-mentioned wire, when connected with Venus and the earth, to be the viſual ray of an obſerver on the earth; it will then point out how the motions of Venus appear in

in the heavens, and the path ſhe appears to us to deſcribe among the fixed ſtars.

Let Venus be placed near her ſuperior conjunction, and the inſtrument in motion, the wire will mark out the apparent motion of Venus in the ecliptic. Thus Venus will appear to move eaſtward in the ecliptic, till the wire becomes a tangent to the orbit of Venus, in which ſituation ſhe will appear to us to be ſtationary, or not to advance at all among the fixed ſtars; a circumſtance which is exceeding viſible and clear upon the planetarium.

Continue turning, till Venus be in her ſuperior conjunction, and you will find by the wire, or viſual ray, that ſhe now appears to move backward in the ecliptic, or from eaſt to weſt, till ſhe is arrived to that part where the viſual ray again becomes a tangent to her orbit. In which poſition, Venus will again appear ſtationary for ſome time; after which, ſhe will commence anew her direct motion.

Hence, when Venus is in the ſuperior part of her orbit, ſhe is always ſeen to move directly, according to the order of the ſigns; but when ſhe is in the inferior part, ſhe appears to move in a contrary direction.

What has been ſaid concerning the motions of Venus, is applicable to thoſe of Mercury; but the conjunctions of Mercury with the ſun, as well as the times of his being direct, ſtationary, or retrograde, are more frequent than thoſe of Venus.

OF THE SUPERIOR PLANETS, AS SEEN FROM THE EARTH.

If you extend your obſervations on the inſtrument to Mars, you will find by the viſual ray, that Mars, when in conjunction, and when in oppoſition, will appear in the ſame point of the ecliptic, whether

whether it is ſeen from the ſun or the earth; and in this ſituation only is it's real and apparent place the ſame, becauſe then only the ray proceeds as if it came from the center of the univerſe.

You will find, that the direct motion of a ſuperior planet is ſwifter the nearer it is to the conjunction, and ſlower when it is nearer to quadrature with the ſun; but that the retrograde motion of a ſuperior planet is ſwifter the nearer it is to oppoſition, and ſlower the nearer it is to quadrature; but at the time of change from direct to retrograde, it's motion becomes inſenſible.

To prove by the planetarium the truth of the Copernican, and abſurdity of the Ptolemaic ſyſtem.

Of all the prejudices which philoſophy contradicts, there is none ſo general as that the earth keeps it's place unmoved. This opinion ſeems to be univerſal, till it is corrected by inſtruction, or by philoſophical ſpeculation. Thoſe who have any tincture of education, are not now in danger of being held by it; but yet they find at firſt a reluctance to believe that there are antipodes, that the earth is ſpherical, and turns round it's axis every day, and round the ſun every year. They can recollect the time when reaſon ſtruggled with prejudice upon theſe points, and prevailed at length, but not without ſome efforts.*

The planetarium gives ocular demonſtration of the motion of the earth about the ſun, by ſhewing that it is thus only that the celeſtial phenomena can be explained, and making the abſurdity of the Ptolemaic ſyſtem evident to the ſenſes of young people.

* Reid's Eſſays on the Intellectual Powers of Man.

people. For this purpoſe, I take off the braſs ball which repreſents the ſun, and put on a ſmall ivory ball in it's place to repreſent the earth, and place a ſmall braſs ball for the ſun, on that arm which carries the earth.

The inſtrument in this ſtate will give an idea of the Ptolemaic ſyſtem, with the earth immoveable in the center, and the heavenly bodies revolving about it in the following order: Mercury, Venus, *the ſun*, Mars, Jupiter, and Saturn. Now in this diſpoſition of the planets, ſeveral circumſtances are to be obſerved, that are contrary to the real appearances of the celeſtial motions, and which therefore prove the falſity of this ſyſtem.

It will appear from the inſtrument, that on this hypotheſis Mercury and Venus could never be ſeen to go behind the ſun, from the earth, becauſe the orbits of both of them are contained between the ſun and the earth; but theſe planets are ſeen to go as often behind the ſun as before it; we may, therefore, from hence conclude, that this ſyſtem is erroneous.

It is alſo apparent in the planetarium, that on this ſcheme theſe planets might be ſeen in conjunction with, or in oppoſition to the ſun, or at any diſtance from it. But this is contrary to experience; for they are never ſeen in oppoſition to the ſun, or on the meridian of London, for inſtance, at midnight, nor ever recede from it beyond certain limits.

Again, on the Ptolemaic ſyſtem all the planets would be at an equal diſtance from the earth, in all parts of their orbits, and would therefore neceſſarily appear always of the ſame magnitude, and moving with equal and uniform velocities in one direction; circumſtances which are known to be repugnant to obſervation and experience.

To rectify the planetarium, or place the planets in their true ſituations, as ſeen from the ſun.

The ſituations of the planets in the heavens are accurately calculated by aſtronomers, and publiſhed in almanacks appropriated to the purpoſe, as the nautical almanack, White's ephemeris, &c. An ephemeris is a diary or daily regiſter of the motions and places of the heavenly bodies, ſhewing the ſituation of each planet at 12 o'clock each day. Theſe ſituations it exhibits both as ſeen from the ſun, and from the earth; but as the former or the heliocentric is the only one of any uſe for this purpoſe, I ſhall here explain ſo much of that part of Mr. White's ephemeris, as will enable you to rectify the planetarium.

Days.	Day increa	Length of Day	Helioc. long. ♄	Helioc. long. ♃	Helioc. long. ♂	Helioc. long. ⊕	Helioc. long. ♀	Helio long. ☿
1	7 4	14 48	27 ♓ 35	2 ♍ 14	27 ♍ 16	11 ♏ 14	8 ♐ 35	1 ♉ 18
7	7 24	15 8	27 47	2 42	29 57	17 2	18 7	26 ♊ 53
13	7 44	15 28	27 59	3 0	2 ♎ 39	21 52	7 37	3 ♌ 4
19	8 0	15 44	28 11	3 37	5 20	28 36	7 ♑ 7	4 ♍ 15
25	8 10	16 0	28 23	4 5	8 3	4 ♐ 22	16 36	0 ♎ 0

In the foregoing table for May, 1790, you have the heliocentric places calculated to every ſix days of the month, which is ſufficiently accurate for general purpoſes. Thus on the 19th, you have Saturn in 28° 11′ of Piſces, Jupiter 3° 37′ of Virgo, Mars in 5° 20′ of Libra, the earth 28° 36′ of Virgo, Venus 7° 7′ of Capricorn, and Mercury 4° 13′ of Virgo; to which places on the ecliptic of the planetarium, the ſeveral planets are to be ſet, and they will then exhibit their real ſituations, both with reſpect to the ſun and the earth for that day.

To uſe the inſtrument as a tellurian, plate 12, *fig.* 1.

The ſun, the earth, and the moon, are bodies, which, from our connection with them, are ſo intereſting to us, that it is neceſſary to enter into a minute detail of their reſpective phenomena. To render this inſtrument a tellurian, all the planets are firſt to be taken off, the piece of wheel-work A B is to be placed on in their ſtead, in ſuch a manner, that the wheel c may fall into the teeth that are cut upon the edge of the ecliptic. The milled nut D is then to be ſcrewed on, to keep the wheel-work firmly in it's place. It is beſt to place this wheel-work in ſuch a manner, that the index E may point to the 21ſt of June, and then to move the globe, ſo that the north pole may be turned towards the ſun.

The inſtrument will then ſhew, in an accurate and clear manner, all the phenomena ariſing from the annual and diurnal motion of the earth: as the globe is of 3 inches diameter, all the continents, ſeas, kingdoms, &c. may be diſtinctly ſeen; the equator, the ecliptic, tropics, and other circles, are very viſible, ſo that the problems relative to peculiar places, may be ſatisfactorily ſolved. The axis of the earth is inclined to the ecliptic in an angle of 66½ degrees, and preſerves it's paralleliſm during the whole of it's revolution. About the globe there is a circle, to repreſent the *terminator*, or boundary between light and darkneſs, dividing the enlightened from the dark hemiſphere. At N O is an hour circle, to determine the time of ſun riſing or ſetting.

The braſs index G repreſents a central ſolar ray; it ſerves to ſhew when it is noon, or when the ſun is upon the meridian at any given place: it alſo ſhews what ſign and degree of the ecliptic on

on the globe the ſun deſcribes on any day, and the parallel it deſcribes.

The plane of the terminator H I paſſes through the center of the earth, and is perpendicular to the central ſolar ray. The index E points out the ſun's place in the ecliptic of the inſtrument for any given day in the year.

To explain the changes of ſeaſons by the tellurian.

The firſt thing to be done, is to rectify the tellurian; or in other words, to put the globe into a poſition ſimilar to that of the earth, for any given day. Thus to rectify the tellurian for the 21ſt of June, turn the handle till the annual index comes to the given day; then move the globe by the arm K L, ſo that the north pole may be turned towards the ſun; and adjuſt the terminator, ſo that it may juſt touch the edge of the arctic circle. The globe is then in the ſituation of the earth for the longeſt day in our northern hemiſphere, the annual index pointing to the firſt point of Cancer and the 21ſt of June; bring the meridian of London to coincide with the central ſolar ray, and move the hour circle N O, till the index L points to XII; we then have the ſituation of London with reſpect to the longeſt day.

Now on gently turning the handle of the machine, the point repreſenting London will, by the rotation of the earth, be carried away towards the eaſt, while the ſun ſeems to move weſtward; and when London has arrived at the eaſtern part of the terminator, the index will point on the hour circle the time of ſun-ſetting for that day; continue to turn on, and London will move in the ſhaded part of the earth, on the other ſide of

the terminator; when the index is again at XII, it is midnight at London; by moving on, London will emerge from the weſtern ſide of the terminator, and the index will point out the time of ſun-riſing, the ſun at that inſtant appearing to riſe above the horizon in the eaſt, to an inhabitant of London.

It will be evident by the inſtrument, while in this poſition, that the central ſolar ray, during the whole revolution of the earth on it's axis, only points to the tropic of Cancer, and that the ſun is vertical to no other part of the earth, but thoſe which are under this tropic.

By obſerving how the terminator cuts the ſeveral parallels of the globe, we ſhall find that all thoſe between the northern and ſouthern polar circles (except the equator) are divided unequally into diurnal and nocturnal arches, the former being greateſt on the north ſide of the equator, and the latter on the ſouth ſide of it.

In this poſition, the northern polar circle is wholly on that ſide the terminator which is neareſt the ſun, and therefore altogether in the enlightened hemiſphere, and the inhabitants thereof enjoy a continual day. In the ſame manner, the inhabitants of the ſouthern polar circle continue in the dark at this time, notwithſtanding the diurnal revolution of the earth; it is the annual motion only which can relieve them from this ſituation of perpetual darkneſs, and bring to them the bleſſings of day, and the enjoyments of ſummer; while in this ſtate the inhabitants in north latitude are neareſt to the central ſolar ray, and conſequently to the ſun's perpendicular beams, and of courſe a greater number of his rays will fall upon any given place, than at any other time; the ſun's rays do now alſo paſs through a leſs quantity of the atmoſphere, which, together with the

the length of the day, and the ſhortneſs of the night, are the reaſons of the increaſe of the heat in ſummer, together with all it's other delightful effects; the ſeaſon when the Lord pours forth his bleſſings upon every living creature in the greateſt abundance.

While the earth continues to turn round on it's own axis once a day, it is continually advancing from weſt to eaſt, according to the order of the ſigns, as is ſeen by the progreſs of the annual index E, which points ſucceſſively to all the ſigns and degrees of the ecliptic; the ſun in the mean time ſeems to deſcribe the ecliptic alſo, going from weſt to eaſt, at the diſtance of ſix ſigns from the earth; that is, when the earth really ſets out from the firſt point of Capricorn, the ſun ſeems to ſet out from the firſt point of Cancer, as is plain in the index.

But as during the annual revolution of the earth, the axis always remains parallel to itſelf, the ſituation of this axis, with reſpect to the ſun, muſt be continually changing.

As the earth moves on in the ecliptic, the northern polar circle gets gradually under the terminator; ſo that when the earth is arrived at the firſt point of Aries, and the annual index is at the firſt point of Libra on the 22d of September, this circle is divided into two equal parts by the terminator, as is alſo every other parallel circle, and conſequently the diurnal and nocturnal arches are equal; this is called the time of equinox, the days and nights are then equal all over the the earth, being each of them 12 hours long, as will be ſeen by the horary index L. The central ſolar ray G having ſucceſſively pointed to all the parallels that may be ſuppoſed to be between the equator and the tropic of Cancer, is at this period

riod perpendicular to the inhabitants that live at the equator.

By continuing to turn the handle, the earth advances in the ecliptic, and the terminator ſhews how the days are continually decreaſing, and the diurnal arches ſhortening, till by degrees the whole ſpace contained by the northern polar circle is on that ſide of the terminator which is oppoſite to the ſun, which happens when the earth is got to the firſt point of Cancer, and the annual index is at the firſt point of Capricorn, on the 21ſt of December. In this ſtate of the globe, the northern polar circle, and all the country within that ſpace, have no day at all; whilſt the inhabitants that live within the ſouthern polar circle, being on that ſide of the terminator which is next the ſun, enjoy perpetual day. By this and the former ſituation of the earth, you will obſerve, that there are nations to whom a great portion of the year is darkneſs, who are condemned to paſs weeks and months without the benign influence of the ſolar rays. The central ſolar ray is now perpendicular to the tropic of Capricorn; the length of the days is inverſely what it was when the ſun entered Cancer, the days being now at their ſhorteſt, and the nights longeſt in the northern hemiſphere; the length of each is pointed out by the horary index.

The earth being again carried on till it enters Libra, and the ſun Aries, we ſhall again have all the phenomena of the equinoctial ſeaſons. The terminator will divide all the parallels into two equal parts; the poles will again be in the plane of the terminator; and conſequently as the globe revolves, every place from pole to pole will deſcribe an equal arch in the enlightened and obſcure hemiſpheres, entering into and going out of

of each exactly at ſix o'clock, as ſhewn by the hour index.

As the earth advances, more of the northern polar circle comes into the illuminated hemiſphere, and conſequently the days increaſe with us, while thoſe on the other ſide of the equator decreaſe, till the earth arrives at the firſt point of Capricorn, the place from which we firſt began to make our obſervations.

To explain the phenomena, that take place in what is called a parallel, direct, and right ſphere.

Take off the globe and it's terminator, and put on in it's place the globe which accompanies the inſtrument, and which is furniſhed with a meridian, horizon, and quadrant of altitude; the edge of the horizon is graduated from the eaſt and weſt, to the north and ſouth points, and within theſe diviſions are the points of the compaſs to the under ſide of this horizon; but at 18 degrees from it another circle is affixed, to repreſent the twilight circle; the meridian is graduated like the meridian of a globe; the quadrant of altitude is divided into degrees, beginning at the zenith, and finiſhing at the horizon.

This globe, if the horizon be differently ſet with reſpect to the ſolar ray, will exhibit the various phenomena ariſing from the ſituation of the horizon with reſpect to the ſun, either in a right, a parallel, or an oblique ſphere; or having ſet the horizon to any place, you will ſee by the central ſolar ray how long the ſun is above or below the horizon of that place, and at what point of the compaſs he riſes, his meridian altitude, and many other curious particulars, of which we ſhall give a few examples.

Set

Set the horizon to coincide with the equator, and place the earth in the first point of Libra; then will the globe be in the position of a parallel sphere, and of the inhabitants of the poles at that season of the year, which inhabitants are represented by the pin at the upper part of the quadrant of altitude; the handle being turned round gently, the earth will revolve upon it's axis, and the solar ray will coincide with the horizon, without deviating in the least to the north or south; shewing, that on the 21st of March the sun does not appear to rise or set to the terrestrial poles, but passes round through all the points of the compass, the plane of the horizon bisecting the sun's disk.

Now place the horizon, so that it may coincide with the poles, and the pin representing an inhabitant be over the equator, the globe in this position is said to be in that of a right sphere; the equator, and all the parallels of latitude, are at right angles, or perpendicular to the horizon; by turning the handle till the earth has completed a year, or one revolution about the sun, we shall perceive all the solar phenomena as they happen to an inhabitant of the equator, which are, 1. That the sun rises at six, and sets at six, throughout the year, so that the days and nights there are perpetually equal. 2. That on the 21st of March, and 22d of September, the sun is in the zenith, or exactly over the heads of the inhabitants. 3. That one half of the year between March and September, the sun is every day full north, and the other half between September and March, is full south of the equator, his meridian altitude being never less than 66½ degrees.

If the pin representing an inhabitant be now removed out of the equator, and set upon any place between it and the poles, the horizon will not then pass through either of the poles, nor coincide

incide with the equator, but cut it obliquely, one half being above, the other half below the horizon; the globe in this ſtate is ſaid to be in that of an oblique ſphere, of which there are as many varieties as there are places between the equator and both poles. But one example will be ſufficient; for whatever appearance happens to one place, the ſame, as to kind, happens to every other place, differing only in degree, as the latitudes differ. Bring the pin, therefore, over London, then will the horizon repreſent the horizon of London, and in one revolution of the earth round the ſun, we ſhall have all the ſolar appearances through the four ſeaſons clearly exhibited, as they really are in nature; that is, the earth ſtanding at the firſt degree of Libra, and the ſun then entering into Aries, the meridian turned to the ſolar ray, and the hour index ſet to XII, you will then have the globe ſtanding in the ſame poſition towards the ſun, as our earth does at noon on the 21ſt of March. If the handle be turned round, when the ſolar ray comes to the weſtern edge of the horizon, the hour index will point VI, which ſhews the time of ſun-ſetting; London then paſſes into, and continues in darkneſs, till the hour index having paſſed over XII hours, comes again to VI, at which time the ſolar ray gains the eaſtern edge of the horizon, thereby defining the time of ſun-riſing; ſix hours afterwards the meridian again comes to the ſolar ray, and the hour index points to XII, thereby evidently demonſtrating the equality of the day and night, when the ſun is in the equinoctial. You may then alſo obſerve, that the ſun riſes due eaſt, and ſets due weſt.

Continuing to move the handle, you will find that the ſolar ray declines from the equator towards the north, and every day at noon riſes higher upon the graduations of the meridian than it did before,

before, continually approaching to London, the days at the ſame time growing longer and longer, and the ſun riſing and ſetting more and more towards the north, till the 21ſt of June, when the earth gets into the firſt degree of Capricorn, and the ſun appears in the tropic of Cancer, riſing about 40 minutes paſt 3 in the morning, and ſetting about 20 minutes paſt 8 in the evening, and after continuing about ſeven hours in the nether hemiſphere, appears riſing in the north-eaſt, as before. From the 21ſt of June to the 22d of September, the ſun recedes to the ſouth, and the days gradually decreaſe to the autumnal equinox, when they again become equal.

During the three ſucceeding months, the ſun continues to decline towards the ſouth pole, till the 21ſt of December, when the ſun enters the tropic of Capricorn, riſing on the ſouth-eaſt point of the compaſs about 20 minutes paſt 8 in the morning, and ſetting about 40 minutes paſt 3 in the evening, at the ſouth-weſt point upon the horizon; after which, the ſun continues in the dark hemiſphere for 17 hours, and then appears again in the ſouth-eaſt, as before. From this chill ſolſtice the ſun returns towards the north, and the days continually increaſe in length till the vernal equinox, when all things are reſtored in the ſame order as at the beginning.

Thus all the varieties of the ſeaſons, the time of ſun riſing and ſetting, and at what point of the compaſs; as alſo the meridian altitude and declination every day of the year, and duration of twilight, and to what place the ſun is at any time vertical, are fully exemplified by this globe and it's apparatus.

Before we quit the phenomena particularly ariſing from the motion and poſition of the earth, let the globe, with the meridian and horizon, be removed,

removed, and the ivory ball which fits upon a pin be placed thereon, to reprefent the earth.

As the axis of this globe ftands perpendicular to the plane of the ecliptic, you will find that the folar ray continually points to the equator of this little ball, and will never deviate to the north or fouth; though by turning the handle, the ball is made to complete a revolution round the fun. This fhews that the earth in this pofition would have the days and nights equal in every part of the globe, all the year long; there would have been no difference in the climates of the earth, no diftinction of feafons; an eternal fummer, or never-ceafing winter, would have been our portion; an unvaried famenefs that would have limited inquiry, and fatiated curiofity; and that the variety of the feafons is owing to it's axis being inclined to the plane of it's orbit.

OF THE LUNARIUM, FIG. 2, PLATE XII.

Having thus illuftrated the phenomena, which arife particularly from the inclination of the earth's axis to the plane of the ecliptic, from it's rotation round it's axis, and revolution round the fun; we now proceed to explain, by this inftrument, the phenomena of the moon. But in order to this, it will be neceffary to fpeak firft of the inftrument, which is put in motion like the preceding one, by the teeth on the fixed wheel; it is alfo to be placed upon the fame focket as the tellurian, and confined down by the fame milled nut.

The floping ring P Q reprefents the plane of the moon's orbit, or path round the earth; fo that the moon in her revolution round the earth does not move parallel to the plane of the ecliptic, but on this inclined plane; the two points of this plane, that are connected by the

brafs

brafs wire, are the nodes, one of which is marked ☊, for the afcending node, the other ☋ for the defcending node. The moon is therefore fometimes on the north, and fometimes on the fouth fide of the ecliptic, which deviations from the ecliptic are called her north or fouth latitude; her greateft deviation, which is when fhe is at her higheft and loweft points, called her limits, is 5 deg. 18 min.; this, with all the other intermediate degrees of latitude, are engraved on this ring, beginning at the nodes, and numbered both ways from them. At each of the nodes, and at about 18 degrees diftant from them, we find this mark ☉, and at about 22 degrees this ☽, to indicate that when the full moon is got as far from the nodes as the mark ☽, there can be no eclipfe of the moon; nor any eclipfe of the fun, when the new moon has paffed the mark ☉; thefe points are generally termed the limits of eclipfes. The nodes of the moon do not remain fixed at the fame point of the ecliptic, but have a motion contrary to the order of the figns.

T V is a fmall circle parallel to the ecliptic; it is divided into 12 figns, and each fign into 30 degrees; this circle is moveable in it's focket, and is to be fet by hand, fo that the fame fign may be oppofite to the fun, that is marked out by the annual index. Thefe figns always keep parallel to themfelves, as they go round the fun, but the inclined plane with it's nodes go backwards, fo that each node recedes thro' all the above figns in about 19 years. R S is a circle, on which are divided the days of the moon's age; X Y is an ellipfis, to reprefent the moon's elliptical orbit, the direct motion of the apogee, or the line of the apfides, with the fituation of the elliptical orbit of the moon, and place of the apogee in the ecliptic at all times.

To

To rectify the lunarium.

Set the annual index on the large ecliptic to the first of Capricorn; then turn the plate, with the moon's signs upon it, until the beginning of Capricorn points directly to the sun; turn the handle till the annual index comes to the first of January; then find the place of the north node in an ephemeris, to which place among the moon's signs, set the north node of her inclined orbit, by turning it till it is in it's proper place in the circle of signs; set the moon to the day of her age.

GENERAL PHENOMENA OF THE MOON.

Having rectified the lunarium for use, on putting it into motion it will be evident,

1. That the moon, by the mechanism of the instrument, always moves in an orbit inclined to that of the ecliptic, and consequently in an orbit analogous to that in which the moon moves in the heavens.

2. That she moves from west to east.

3. That the white or illuminated face of the moon is always turned towards the sun.

4. That the nodes have a revolution contrary to the order of the signs, that is, from Aries to Pisces; that this revolution is performed in about nineteen years, as in nature.

5. That the moon's rotation upon her axis is effected and completed in about $27\frac{1}{2}$ days; whereas it is $29\frac{1}{2}$ days from one conjunction with the sun to the next.

6. That every part of the moon is turned to the sun, in the space of her monthly or periodic revolution.

To be more particular. On turning the handle, you will obſerve another motion of the earth, which has not yet been ſpoken of, namely, it's monthly motion about the common center of gravity between the earth and moon, which center of gravity is repreſented by the pin Z. From hence we learn, that it is not the center of the earth which decribes what is called the annual orbit, but the center of gravity between the earth and moon, and that the earth has an irregular, vermicular, or ſpiral motion about this center, ſo that it is every month at one time nearer to, at another further from the ſun. It is evident from the inſtrument, that the moon does not regard the center of the earth, but the center of gravity, as the center of her proper motion; that the center of the earth is furtheſt from the ſun at new moon, and neareſt at the full moon; that in the quadratures the monthly parallax of the earth is ſo ſenſible, as to require a particular equation in aſtronomical tables. Theſe particulars were firſt applied to the orrery, by the late ingenious Mr. Benjamin Martin.

To explain the phaſes of the moon.

The moon aſſumes different phaſes to us, 1. on account of her globular figure; 2. on account of the motion in her orbit, between the earth and the ſun: for whenever the moon is between the earth and the ſun, we call it new moon, the enlightened part being then turned from us; but when the earth is between the ſun and the moon, we then call it full moon, the whole of the enlightened part being then turned towards us.

The phaſes of the moon are clearly exhibited in this inſtrument; for here we ſee that half which is oppoſite to the ſun is always dark, while that which

which is next to the ſun is white, to repreſent the illuminated part. Thus when it is new moon, you will ſee the whole white part next the ſun, and the dark part turned towards the earth, ſhewing thereby it's diſappearance, or the time of it's conjunction and change: on turning the handle, a ſmall portion of the white part will begin to be ſeen from the earth, which portion will increaſe towards the end of the 7th day, when you will perceive that half of the light, and half of the dark ſide, is turned towards the earth, thus illuſtrating the appearance of the moon at the firſt quarter. From hence the light ſide will continually ſhew itſelf more and more in a gibbous form, till at the end of fourteen days the whole white ſide will be turned towards the earth, and the dark ſide from it, the earth now ſtanding in a line between the ſun and moon; and thus the inſtrument explains the oppoſition, or full moon. On turning the handle again, ſome of the ſhaded part will begin to turn towards the earth, and the white ſide to turn away from it, decreaſing in a gibbous form till the laſt quarter, when the moon will appear again as a creſcent, which ſhe preſerves till ſhe has attained another conjunction.

In this lunarium the moon has always the ſame face or ſide to the earth, as is evident from the ſpots delineated on the ſurface of the ivory ball, revolving about it's axis in the courſe of one revolution round the earth; in conſequence of which, the light and dark parts of the moon appear permanent to us, and the phaſes are ſhewn as they appear in the heavens.

As the earth turns round it's axis once in 24 hours, it muſt in that time exhibit every part of it's ſurface to the inhabitants of the moon, and therefore it's luminous and opake parts

will

will be ſeen by them in conſtant rotation. As that half of the earth which is oppoſed to the ſun is always dark, the earth will exhibit the ſame phaſes to the lunarians that we do to them, only in a contrary order, that when the moon is new to us, we ſhall be full to them, and *vice verſa.* But as one hemiſphere only of the moon is ever turned towards us, it is only thoſe that are in this hemiſphere who can ſee us; our earth will appear to them always in one place, or fixed in the ſame part of the heavens; the lunarians in the oppoſite hemiſphere never ſee our earth, nor do we ever view that part of the moon which they inhabit. The moon's apparent diurnal motion in the heavens is produced by the daily revolution of our earth.

If we conſider the moon with reſpect to the ſun, the inſtrument ſhews plainly that one half of her globe is always enlightened by the ſun; that every part of the lunar ball is turned to the ſun, in the ſpace of her monthly or periodical revolution; and that therefore the length of the day and night in the moon is always the ſame, and equal to $14\frac{3}{4}$ of our days. When the ſun ſets to the lunarians in that hemiſphere next the earth, the terreſtrial moon riſes to them, and they can therefore never have any dark night; while thoſe in the other hemiſphere can have no light by night, but what the ſtars afford.

OF THE PERIODICAL AND SYNODICAL MONTH.

The difference between the periodical month, in which the moon exactly deſcribes the ecliptic, and the ſynodical, or time between any two new moons, is here rendered very evident. To ſhew this difference, obſerve at any new moon her place in

in the ecliptic, then turn the handle, and when the moon has got to the ſame point in the ecliptic, you will ſee that the dial ſhews $27\frac{1}{3}$ days, and the moon has finiſhed her periodic revolution. But the earth at the ſame time having advanced in it's annual path about 27 degrees of the ecliptic, the moon will not have got round in a direct line with the ſun, but will require 28 days and 4 hours more, to bring it into conjunction with the ſun again.

OF ECLIPSES OF THE SUN AND MOON.

There is nothing in aſtronomy more worthy of our contemplation, nor any thing more ſublime in natural knowledge, than rightly to comprehend thoſe ſudden obſcurations of the heavenly bodies, that are termed eclipſes, and the accuracy with which they are now foretold. "One of the chief advantages derived by the preſent generation from the improvement and diffuſion of philoſophy, is delivery from unneceſſary terror, and exemption from falſe alarms. The unuſual appearances, whether regular or accidental, which once ſpread conſternation over ages of ignorance, are now the recreations of inquiſitive ſecurity. The ſun is no more lamented when it is eclipſed, than when it ſets; and meteors play their coruſcations without prognoſtic or prediction."

We have already obſerved, that the ſun is the only real luminary in the ſolar ſyſtem, and that none of the other planets emit any light but what they have received from the ſun; that the hemiſphere which is turned towards the ſun is illuminated by his rays, while the other ſide is involved in darkneſs, and projects a ſhadow, which ariſes from the luminous body.

When the ſhadow of the earth falls upon the moon, it cauſes an eclipſe of the moon; when the ſhadow of the moon falls upon the earth, it cauſes an eclipſe of the ſun.

An eclipſe of the moon, therefore, never happens but when the earth's opake body interpoſes between the ſun and the moon, that is, at the full moon; and an eclipſe of the ſun never happens but when the moon comes in a line between the earth and the ſun, that is, at the new moon.

From what we have already ſeen by the inſtrument, it appears that the moon is once every month in conjunction, and once in oppoſition; from hence it would appear, that there ought to be two eclipſes, one of the ſun, the other of the moon, every month; but this is not the caſe, and for two reaſons, firſt, becauſe the orbit of the moon is inclined in an angle of about 5 degrees to the plane of the ecliptic; and ſecondly, becauſe the nodes of this orbit have a progreſſive motion, which cauſes them to change their place every lunation. Hence it often happens, that at the times of oppoſition or conjunction the moon has ſo much latitude, or what is the ſame thing, is ſo much below or above the plane of the ecliptic, that the light of the ſun will in the firſt caſe reach the moon, without any obſtacle, and in the other the earth; but as the nodes are not fixed, but run ſucceſſively through all the ſigns of the ecliptic, the moon is often, both at the times of conjunction and oppoſition, in or very near the plane of the ecliptic; in theſe caſes an eclipſe happens, either of the ſun or moon, according to her ſituation. The whole of this is rendered clear by the lunarium, where the wire projecting from the earth, ſhews when the moon is above, below, or even with the earth, at the times of conjunction and

and oppoſition, and thus when there will be, or not, any eclipſes.

The diſtance of the moon from the earth varies ſenſibly with reſpect to the ſun; it does not move in a circular, but in an elliptic orbit round us, the earth being at one of the foci of this curve. The longer axis of the lunar orbit is not always directed to the ſame point of the heavens, but has a movement of it's own, which is not to be confounded with that of the nodes; for the motion of the laſt is contrary to the order of ſigns, but that of the line of apſides is in the ſame direction, and returns to the ſame point of the heavens in about nine years. This motion is illuſtrated in the lunarium by means of the braſs ellipſis X Y, which is carried round the earth in little leſs than nine years; thus ſhewing the ſituation of the elliptical orbit of the moon, and the place of the apogee in the ecliptic.

OF A NEW TERRESTRIAL GLOBE,*

And of a new Apparatus adapted thereto, for ſolving, in an eaſy and natural manner, the ſeveral Phenomena of the Sun, Moon, and Earth.

Though globes have ever been conſidered as the beſt inſtruments for conveying general ideas of aſtronomy and geography, yet have they always been mounted in a way that muſt perplex and confuſe the learner, and furniſh him with ideas that are altogether falſe, and contrary to the nature of things.

 That

* The terreſtrial globe was firſt improved by my father, and placed in a fixed poſition, &c. The floating meridian and horizon were added by Mr. Newman.

That you may clearly perceive the great advantages of a globe mounted like that before you, I ſhall firſt point out a few of the imperfections of globes mounted in the *common way*, and how very unfit they are for the purpoſes of inſtruction.

Now, in the firſt place, what is rectifying a globe thus mounted, but a continual abſurdity? for to rectify the globe to any particular latitude, the axis of the earth is continually ſhifted from one falſe poſition to another, the mind of the pupil is confuſed, and he with difficulty conceives, that the axis of the earth never varies it's poſition, but always preſerves the ſame inclination to the plane of it's orbit.

The broad paper circle of the common globes is deſigned to repreſent the *ecliptic* and the *horizon*; but on examination you will find it repreſents neither the one nor the other. Now the ecliptic is the apparent path of the ſun, to which the earth's axis always makes an angle of 66½ degrees; now by ſhifting the axis of the globe, to rectify for the latitude, this circle can never be in it's poſition as ecliptic, except when the axis is at 66½ degrees, and conſequently cannot be uſed as the ecliptic. Now let us conſider it as the *horizon*. Now every place is always in the zenith of it's horizon, and the place and horizon always move together; but in the common globes the broad paper circle is only the horizon in one ſituation, that is, when the place is in the zenith; after having rectified the globe to the latitude, the moment you move the globe, the broad paper circle is no longer the horizon. Thus is it plain, that this circle cannot with propriety be conſidered either as horizon or ecliptic. As if it were to multiply confuſion, a circle is laid down on the terreſtrial globe to repreſent the ecliptic, and uſed as ſuch in ſolving problems upon the common

common globes, though it involves the pupil in numerous abſurdities: thus having marked the ſun's place in the ecliptic, and rectified the globe to the latitude, then turn the globe, and the ſun and earth have a diurnal motion together; of courſe, if you have day when you begin, you will have the ſame during the whole twenty-four hours. Many other errors might eaſily be pointed out, but theſe are ſufficient to ſhew you, that no one can be properly taught by globes ſo mounted. I would alſo juſt obſerve to you, that the ideas of a parallel, oblique, and right ſphere are abſurd, with reſpect to the globe of the earth, as it has in reality but one poſition.

The globe before you, *fig.* 2, *pl.* 13, does not hang in a frame like the common globes, but is mounted on a pedeſtal, and is ſupported by, and moveable on, an axis which is inclined $66\frac{1}{2}$ degrees to the ecliptic, and of courſe is always parallel to the axis of the earth, ſuppoſing the path of the globe to be parallel to the ecliptic. On the pedeſtal, but under the globe, is a graduated circle, marked with the ſigns and degrees of the ecliptic; adjoining thereto is a circle of months and days, anſwering to every degree of the ecliptic; within this circle is the ſun's declination for every day of the month.

There is a moveable arm A B, which being ſet to the day of the month, immediately points out the ſun's place in the ecliptic, and his declination. On this moveable arm, but near the index, you obſerve a pillar; on the top of the pillar is fixed a ſmall ball, through which a ſteel wire paſſes, to repreſent a *ray* proceeding from the center of the ſun.

Round the globe is a circle to repreſent the *horizon* of any place; and at right angles to this horizon, is fixed a ſemicircle, to anſwer for a general meridian. The middle point of this ſemicircle

circle anſwers for the ſituation of any inhabitant on the earth, for which reaſon a ſteel pin is fixed over the middle point of this ſemicircle.

One ſuppoſition only is neceſſary for performing every problem with this globe; namely, that a ſpherical luminous body will enlighten one half of a ſpherical opake body, and conſequently that a circle at right angles to the central ſolar ray, and dividing the globe in half, will be a terminator ſhewing the boundaries of light and darkneſs for any given day.

For this purpoſe, at the end of the moveable arm oppoſite to the ſun, there is a pillar, from the top of which projects a piece to carry a circle that ſurrounds the globe, and always divides it into equal portions, ſeparating the enlightened from the dark parts. 18 degrees behind this circle, but parallel thereto, is another circle, to repreſent the limits of twilight.

There are two plates under the globe, which are turned by the diurnal revolution thereof; each of them is divided into twice twelve hours and parts of an hour, to anſwer for the hours of day; on the outſide are laid down the degrees of longitude for every hour; ſo that theſe circles give you at ſight the hour of the day or night, at any two places on the globe, and the difference of longitude correſponding thereto.

There is one thing more relative to the globe, which renders it a *planetary globe;* for by ſetting this pillar, *fig.* 4, *pl.* 13, to the place of any planet in the ecliptic, and the ball to the latitude of the planet, it will ſolve all problems relative to that planet, or the moon; as it does for the ſun, by means of a central ſolar ray.

To rectify this globe, ſet the diviſion under the repreſentative inhabitant over the given place, ſet the ſolar index to the day of the month, then turn

turn the globe round on the axis till the meridian coincides with the central ſolar ray, and the hour index under the globe to XII; and this globe is then in the poſition of our globe, with reſpect to the ſun and that place, &c.

Place the inhabitant on the weſtern ſide of the terminator, and he will ſee the ſun or the central ſolar ray riſing in the horizon, and this ray will mark thereon the ſun's amplitude, and the hour circle gives you the hour and minute of the ſun's riſing on that day and place; turn the globe gradually till the meridian coincides with the central ſolar ray, and the point will mark out the ſun's meridian altitude for that day. As the globe goes on, the altitude decreaſes, and when the inhabitant is arrived at the other ſide of the terminator, the ſolar ray is in the horizon, and points out the ſun's amplitude, and you have the time of his ſetting on the hour circle. If you proceed to turn the globe till the inhabitant is under that circle, which is behind the terminator, the hour circle gives the time that twilight finiſhes. The ſun's altitude for any given time of the day, is obtained by ſtopping the globe when the index points out that hour, and the quadrant of altitude over the inhabitant, and then bringing it to the central ray, which will point out thereon the altitude for that hour.

In this manner you may ſolve the ſame queſtions for any other place, or any other day, always obſerving, 1. To fix the inhabitant over the given place. 2. To ſet the ſun's annual index to the given day of the month. 3. To bring the meridian to the central ſolar ray, and the hour index under the globe to XII. By placing the ſmall pillar to the moon's place in the ecliptic, and the ball to her latitude, the ſame problems may be ſolved

at

at the ſame time for the moon; and ſo reſpectively of any other planet.

By this globe, a perſon entirely unacquainted with aſtronomy, may in a few hours acquire a competent notion of the principal phenomena, and to ſolve the greateſt part of the moſt intereſting problems concerning the ſun, moon, and planets.

OF THE CELESTIAL GLOBE, FIG. 3, PLATE 13.

As the terreſtrial globe is mounted to correſpond exactly with the globe of our earth, and every problem anſwered as they are really occaſioned by the annual and diurnal motion of the earth; ſo the celeſtial globe, to be conformable to nature, ſhould be as nearly as poſſible an exact imitation of the heavens, and their ſituation with reſpect to the earth; which is far from being the caſe with the common globes.

To make the celeſtial globe thus conformable to nature, it ſhould have no motion; the appearances of motion in the firmament ariſe from the diurnal motion of the earth; it is plain, therefore, that whatſoever gives a true repreſentation of the heavens, will have no motion. The celeſtial globe before you, is therefore fixed on an axis, making, like that of the terreſtrial globe, 66½ degrees with the plane of the ecliptic; and the ecliptic on this globe exactly coincides with the ſun's apparent path round the earth. All problems concerning the ſun, moon, and planets, are performed by the terreſtrial globe. This globe needs only be uſed for the ſtars, and one or two problems will give you a ſufficient idea of the manner of ſolving all that relates to the ſtars.

To find the latitude and longitude of a given ſtar.

Find

Find the ſtar on the globe, and then place the clip on the ecliptic plate, ſlide the ſiderial index till it is exactly over the ſtar, and the latitude is ſhewn on the arch, and the longitude, by the index, on the ecliptic.

To find the riſing, ſetting, amplitude, and meridian altitude of the ſame ſtar. Take the clip from the celeſtial globe, and put it to the ſame degree of longitude on the terreſtrial ecliptic plate; turn the globe on it's axis, and the time of it's riſing and ſetting is immediately pointed out by the hour index; it's amplitude is ſhewn on the horizon; it's meridian altitude, by the meridian; and it's azimuth and altitude for any hour, by applying the quadrant of altitude under the ſiderial index for that hour.

I ſhall conclude my Lectures on theſe *inſtruments* with ſome obſervations that naturally ariſe from conſidering the *art* and *ingenuity* with which they are conſtructed. For when we ſee materials working with an art and contrivance that is not in their nature, we are at once convinced, that a ſuperior intelligence has been concerned in their arrangement, &c.

Thus alſo in nature, whatever bears the marks of a wiſdom not belonging to the known cauſes producing it, may be properly ſtiled *providential*: for when agents void of wiſdom act wiſely, it is plain there muſt be ſome hand to conduct them, though we may not be able to perceive by what ſprings or channels of communication it operates. There wants, therefore, no long train of reaſoning to lead us into the knowledge of a *providence*. Penetration and cloſeneſs of thought have no further uſe in this caſe, than to diſcover the fallacy of thoſe ſophiſms, wherein infidel writers endeavour to overcloud the moſt apparent truths. The plain man needs no aſſiſtance here from the philoſopher,

philofopher, but may fay to him, as Diogenes did to Alexander, "Only pleafe to ftand out of my funfhine."

* Intelligence is manifefted two ways, either by means fupplied to anfwer the end we conceive to have been had in view, though we do not difcern the method by which they were prepared; or elfe by the contrivance apparent in productions, though we do not fee what end they anfwer: the former more particularly give us the difplay of providence, the latter of the wifdom wherewith it is adminiftered.

If you faw a houfe ftored with furniture, utenfils, and victuals; the gardens planted with herbs and fruit trees; the grounds ftocked with cows, horfes, deer, and poultry, all in a manner fitted for the entertainment and convenience of a family; you would certainly conclude, there was fome mafter who had taken care to provide for the ufes whereto they were refpectively proper. Or if an ignorant perfon went into a room, where among fcales, weights, compaffes, rules, and other things of common ufe, he fhould find quadrants, theodolets, armillary fpheres, planetariums, tellurians, &c. &c. of whofe ufe, as well as of the figures upon them, he was entirely ignorant; yet he would know without being told, that they were the works of fome artificer proceeding with fkill and contrivance, and who made them for purpofes worthy the care with which they were finifhed.

In this manner we conftantly reafon upon common occafions, and there wants only a proper attention to lead us into the like train of thinking upon the phenomena of vifible nature. For there you may perceive ample provifion made in vaft variety for the numerous family of Adam; corn, fruit,

* Tucker's Light of Nature, vol. 3, part 1, page 192.

fruit, herbs, cattle and fowl, for our ſuſtenance; wool, flax, and cotton, for our cloathing; drugs and ſimples for our relief; air for our breathing; timber, ſtone, lime, and brick-earth, for our habitation; wood and coal for our firing; beaſts of burden for our aſſiſtance; winds to purify our atmoſphere, to refreſh our heats, and waft us from ſhore to ſhore; variety of climates and ſoils to bear us a produce of every kind; dews and rains to make them yield us their increaſe. The ſea, that original ſource of water, ſo neceſſary to us for many uſes, ſerves likewiſe to aſſociate diſtant nations by opening the communication of commerce. The ſun diffuſes his warmth and light to cheriſh us. The diſtant ſtars guide us over the boundleſs ocean, and the inhoſpitable deſert; extend the fields of ſcience to an immenſity of ſpace, and turn the rugged brow of night into a chearful ſcene of contemplation.

Even within the narrow compaſs of *our own bodies*, we carry about no inconſiderable ſtores, without which we could not receive benefit from thoſe around us. We have engines of digeſtion and ſecretion, ſprings and channels of circulation, limbs for inſtruments of action, bones for our ſupport and protection, organs of ſpeech for our mutual intercourſe. What a multitude of veſſels, glands, and ducts, to concoct and diſtribute our aliment! What artificial ſtructure and excellent diſpoſition of muſcles and joints to ſerve for inſtruments of action! What amazing nicety in the organs of ſenſe! The *eye* with her humours and coats mathematically arranged, and duly proportioned one among the other; the *ear* in winding modulating the vibrations of air into ſounds; the *nerves* in imperceptible threads running every where through the fleſhy parts, yet returning their notices without impediment from the furtheſt ex-

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tremities of our limbs! And all this complicated machine, containing an infinitude of multiform works, is bound up in a ſmall compaſs, yet with ſuch ſtupendous ſkill, that they do not interfere with each other's operations, nor fall into diſcord upon our motions!

We have appetite to ſtimulate, ſenſes to inform, the faculties of comparing, diſtinguiſhing, judging to enlighten, and reaſon to direct us. In the capacity of our ſenſes and affections, we have ſources of pleaſure, enjoyment, and innocent mirth.

In the multitude of the objects of creation, we find a proviſion made and ſuited to our various organs, taſtes, and faculties, a fund for bodily ſupport, ſubjects for intellectual inquiries and mental gratification. "Which ſhall we admire moſt, the multitude of our organs, their finiſhed form and faultleſs order, or the power which the mind exerciſes over them? Ten thouſand veins are put into her hands, and yet ſhe manages and conducts them all without the leaſt perplexity or irregularity, with a promptitude, a conſiſtency, that nothing elſe can equal; touching every ſpring of the human machine with the moſt maſterly ſkill, though ſhe knows nothing of the nature of her inſtrument, or the proceſs of her operation.

If you turn your eyes upon the vegetable tribes, you perceive them, in countleſs multitudes of trees, ſhrubs, weeds, moſſes, &c. each growing, ſpreading, and flouriſhing, by laws adapted to it's own kind; and all worked with ſuch exactneſs and nicety of art, as the greateſt human ingenuity could not imitate; their ſap veſſels curiouſly woven within the ſtem, and diſperſed among the roots and branches; their leaves wrought finer than needle-work. The fineſt works of the loom and the needle, when examined with a microſcope, appear ſo rude and coarſe, that a ſavage might be aſhamed

ashamed to wear them: but when the work of God is brought to the same test, we see how fibres, too minute for the naked eye, are composed of others still more minute; and these again of others; till the primordial threads, or first principle of the texture, are utterly undiscernable; while the whole substance presents a celestial radiance in it's colouring, as if it were intended for the cloathing of an angel.

Yet are these wonders of the vegetable world surpassed by those of the animal, whose frame contains a more complicated machinery, capable of more admirable play: for besides the engines of growth and nutriment analagous in both, the animal is furnished with organs of sensation, and instruments of activity. What a richness of invention is displayed in the variety of their forms, and the diversity of their cloathing.—Nor can we help remarking those surprising instincts that severally guide them to their harbours, their foods, their ways of breeding and preservation, instruct them to build their nest, to make their comb, to spin their webs, and provide for the future without knowledge of their wants.

Nor must we omit the uses and qualities assigned to animals, that we can turn commodiously to our advantage; we have not to seek our wool from the fierce lion, nor want the untameable tyger to plow our grounds; but the ox, the horse, and the sheep, have docility and manageableness given them for their characteristics. Creatures saleable in the market are more prolific than those of the savage kind. Poultry and rabbits keep within their accustomed purlieus; but nobody knows where to find the coarse-grained heron, or the worthless cuckoo.*

O Lord,

* Rev. W. Jones's Sermons, vol. 2, p. 63.

O Lord, how manifold are thy works; in wisdom hast thou made them all; the earth is full of thy riches! All creatures wait upon thee, that thou mayest give them their meat in due season. When thou givest it them they gather it, and when thou openest thine hand they are filled with good. How great and beautiful is this idea! The hand of man scatters food to the few creatures that are about him; but when the hand of *God* is opened, a world is fed and satisfied.*

Endless are the instances which might be here brought forwards as evidences of a superintending providence. I shall however only mention another instance, namely, that of adapting causes, acting blindly through a long series of operation, yet acting with such wonderful exactness, that things are brought into the same admirable order, as if each had been acted on immediately by an intelligent hand. This instance is of such importance, so heightens our idea of the contrivance of the *Almighty*, and at the same time so effectually overturns many of the objections of minute philosophers, that I shall endeavour to place it before you in a strong and clear light.

Every one is sensible that there is much contrivance and art in a common watch; not that he thinks that there is any skill or understanding in the parts thereof, combining to point out the hour and minute; for he knows that all their movements follow necessarily from the number of the teeth, their situation, &c. and that the numbers must have been calculated, the form given to the teeth, &c. &c. by some skilful artist. Now suppose him carried down into a mine, where he found an engine that collected the metallic particles from their ores,

* Rev. W. Jones's Sermons, vol. 2, p. 104.

ores, worked them up into ſprings, and wheels, and dial plates, and hands; and diſpoſed them ſo as to form a perfect watch, all by a mechanical operation; he will alter his opinion, and ſtand convinced, that watches might be made without hands, by a blind mechaniſm, proceeding without thought or contrivance of the work it performed. But though he loſt his idea of ingenuity being requiſite for making watches upon ſeeing them generated by mechanical cauſes, he would be ſatisfied, *a much greater* muſt have been employed in conſtructing the engine, than he had judged needful, while he conſidered them as made by hand, with hammers, files, pincers, and other inſtruments of the trade.

It may be here objected, that this is a romantic ſuppoſition, for that nobody ever ſaw an engine that will make watches. This is true, nobody ever yet ſaw ſuch an engine, nor I believe ever will; for it would require much greater ſkill to contrive, than the ſons of men are maſters of: nevertheleſs *we have all ſeen engines that have brought to perfection work more curious and admirable.*

Examine a fruit or a ſeed, and you will find it nicely enveloped in ſeveral teguments, furniſhed with fibres and juices ranged in their exact order, provided with ſprings capable of expanding into ſtem, branches, and leaves, of one particular form and contexture. The plant that bears it, may be conſidered as an engine, fitted with roots to gather the nutritious particles from the earth; ſap veſſels to concoct and circulate the juices; twigs to work them into a bud or flower, for perfecting this ſurprizing machine.

Conſider the body of a fowl, what an abundance of work it contains, adapted for carrying on the buſineſs of digeſtion, circulation, and animal motion, in greater art and variety than any clock-work that ever yet was made by human contri-

vance.

vance. What then is an egg, but an engine constructed to fashion all these complicated works, and arrange them in their proper order? or what else the matrix of the parent bird, besides another engine contrived for making eggs?

Indeed the whole system of nature may be considered as a stupendous engine, containing, besides the works appropriated to the generation of organized compositions, a countless multitude of others, properly fitted and disposed to assist in carrying on the plan of vegetation and vital engines, all conspiring in their several *uses* to carry on the general plan of divine providence.

If you consider this matter properly, you will soon be convinced, that this prolific principle is not from the seed, nor from the sun, but from God the Creator, and that not only when created at first, but continually afterwards; for *support* is *perpetual* creation, as subsistence is perpetual existence.

Each of the links that compose the mighty chain of nature, while it connects, illustrates those that border next upon it, and displays the *wisdom* of the *Creator* both in it's own frame and state, and the connections it holds with the orders above and below it.

The continued support, the constant preservation, and repeated renovation of creatures both rational and irrational, animate and inanimate; their regular arrangement, and exact adaption to their respective situations, evince a ruling government and supreme governor, and that the whole universe of being is connected, comprehended, and pervaded by the influence of our God.

You will hence also perceive the error of those who resolve nature into mere mechanical operations, as if nature could operate of herself to produce effects: for you have seen it clearly proved,

proved, that there is no operation in nature, but what is carried on under the influence and direction of the Supreme Being; that there is no inferior agent but what is ſubject to the controul of a merciful and all wiſe God, the real and living operator by the ſubjects of the material world.

As well might you ſuppoſe light and heat equally and regularly diſpenſed, as at preſent, "with ſun and ſtars in mid-ſea ſunk," as to ſuppoſe nature living without a principle of life and being flowing from no fountain. The whole ſeries of cauſes and effects proves, that nature has no will of it's own to guide it's motions or direct it's courſes. Does the ſun know when to riſe? or does the ſea preſcribe to itſelf it's juſt limits how far it ſhall go, and no farther?

The more you contemplate the vaſt concurrence of cauſes that join in producing the ſeveral operations of nature, the more eaſily will you be ready to believe with *Plato*, that the whole world is one tiſſue of cauſes and effects, wherein nearly, or remotely, every thing has an influence upon every thing; and thence conclude, that the young ravens are fed, and the lilies of the field arrayed in the glory of Solomon, by divine proviſion; and that of two ſparrows which are ſold for a farthing, not one of them falleth to the ground, not a hair is loſt out of the number upon our heads, without the permiſſion or appointment of our HEAVENLY FATHER.

LECTURE XLIV.

OF THE FIXED STARS.

No part of the univerſe gives ſuch enlarged ideas of the ſtructure and magnificence of the heavens, as the conſideration of the number, magnitude, and diſtance of the fixed ſtars

We admire indeed, with propriety, the vaſt bulk of our own globe; but when we conſider how much it is ſurpaſſed by moſt of the heavenly bodies, what a point it degenerates into, and how little more even the vaſt orbit in which it revolves would appear, when ſeen from ſome of the fixed ſtars, we begin to conceive more juſt ideas of the extent of the univerſe, and the boundaries of creation.

The moſt conſpicuous and brighteſt of the fixed ſtars of our horizon is Sirius. The earth, in moving round the ſun, is 190 millions of miles nearer to this ſtar in one part of it's orbit, than in the oppoſite; yet the magnitude of the ſtar does not appear to be in the leaſt altered, or it's diſtance affected by it; ſo that the diſtance of the fixed ſtars is great beyond all computation. The unbounded ſpace appears filled at proper diſtances with theſe ſtars, each of which is probably a ſun, with attendant planets rolling round it. In this view, what, and how amazing, is the ſtructure of the univerſe!

Though the fixed ſtars are the only marks by which aſtronomers are enabled to judge of the courſe of the moveable ones, and we have aſſerted their

their relative poſitions do not vary ; yet this aſſertion muſt be confined within ſome limits, for many of them are found to undergo particular changes, and perhaps the whole are liable to ſome peculiar motion, which connects them with the univerſal ſyſtem of created nature. Dr. Herſchel even goes ſo far as to ſuppoſe, that there is not, in ſtrictneſs of ſpeaking, one fixed ſtar in the heavens ; but that there is a general motion of all the ſtarry ſyſtems, and conſequently of the ſolar one among the reſt.

There are ſome ſtars, whoſe ſituation and place were heretofore known, and marked with preciſion, that are no longer to be ſeen ; new ones have alſo been diſcovered, that were unknown to the ancients, while numbers ſeem gradually to vaniſh. There are others which are found to have a periodical increaſe and decreaſe of magnitude ; and it is probable, that the inſtances of theſe changes would have been more numerous, if the ancients had poſſeſſed the ſame accurate means of examining the heavens, as are uſed at preſent.

New ſtars offer to the mind a phenomenon more ſurprizing, and leſs explicable, than almoſt any other in the ſcience of aſtronomy; I ſhall ſelect a few inſtances of the more remarkable ones, for your inſtruction : a conſideration of the changes that take place, at ſo immenſe a diſtance as the ſtars are known to be from you, may elevate your mind to conſider the immenſity of HIS power, who regulates and governs all theſe wide extended motions ; " who hath meaſured the waters in the hollow of his hand, and meted out heaven with a ſpan."

" Who turns his eye, on nature's midnight face,
But must inquire——What hand behind the ſcene,

What ARM ALMIGHTY, put theſe wheeling globes
In motion, and wound up the vaſt machine?"

It was a new ſtar diſcovered by Hipparchus, the chief of the ancient aſtronomers, that induced him to compoſe a catalogue of the fixed ſtars, that future obſervers might learn from his labours, whether any of the known ſtars diſappeared, or new ones were produced. The ſame motives engaged the illuſtrious Tycho Brahe to form, with unremitting labour and aſſiduity, another new catalogue of the ſtars.

Of new ſtars, the firſt of which we have a good account, is that which was diſcovered in the conſtellation of Caſſiopea, in the month of November of the year 1572, a time when aſtronomy was ſufficiently cultivated, to enable the aſtronomers to give the account with preciſion. It remained viſible about ſixteen months; during this time, it kept it's place in the heavens, without the leaſt variation. It had all the radiance of the fixed ſtars, and twinkled like them; and was in all reſpects like Sirius, excepting that it ſurpaſſed it in brightneſs and magnitude. It appeared larger than Jupiter, who was at that time in his perigee; and was ſcarce leſs bright than Venus.

It was not by degrees that it acquired this diameter, but ſhone forth at once of it's full ſize and brightneſs, as if of inſtantaneous creation. It continued about three weeks in full and entire ſplendor, during which time it might be ſeen even at noon day, by thoſe who had good eyes, and knew where to look for it. Before it had been ſeen a month, it became viſibly ſmaller, and from thence continued diminiſhing in magnitude till March, 1574, when it entirely diſappeared. As it decreaſed in ſize, it varied in colour; at firſt, it's light was white, and extremely bright;

it

it then became yellowiſh, afterwards of a ruddy colour, like Mars; and finiſhed with a pale livid white, reſembling that of Saturn.

In 1596, Fabricius obſerved a new ſtar in the neck of the Whale: he firſt ſaw it in Auguſt, and it diſappeared in October of the ſame year. In 1637, Phocyllides Holwarda obſerved it again, and not knowing that it had been ſeen before, took it for a new diſcovery: he watched it's place in the heavens, and ſaw it appear again the ſucceeding year, nine months after it's diſappearance. It has been ſince found to be every year very regular in it's period, except that in 1672 it was miſſed by Hevelius, and not ſeen again till 1676. Bullialdus having compared together the obſervations which had been made of it from 1638 to 1666, determined the periodical time between this ſtar's appearing in it's greateſt brightneſs, and returning to it again, to be 333 days; obſerving further, that this ſtar did not appear at once in it's full magnitude, or brightneſs, but by degrees arrived at them. He alſo framed an hypotheſis, to account for theſe periodic changes.

Three changeable, or re-apparent ſtars have been diſcovered in the conſtellation of the Swan; the firſt was ſeen by Janſonius, in 1600; the ſecond was diſcovered in 1670; the third by Kirchius, in 1686.

In the latter end of September, 1604, a new ſtar was diſcovered near the heel of the right foot of Serpentarius. There were in that part of the heavens, at that time, the three ſuperior planets, which ſo engaged the attention of aſtronomers, that no appearance thereabouts could have long eſcaped them. Kepler, in deſcribing it, ſays, that it was preciſely round, without any kind of hair, or

tail; that it was exactly like one of the ſtars, except that in the vividneſs of it's luſtre, and the quickneſs of it's ſparkling, it exceeded any thing he had ever ſeen before. It was every moment changing into ſome of the colours of the rainbow, as *yellow*, *orange*, *purple*, and *red*; though it was generally *white*, when it was at ſome diſtance from the vapours of the horizon. Thoſe in general who ſaw it, agreed that it was larger than any other fixed ſtar, or even any of the planets, except Venus: it preſerved it's luſtre and ſize for about three weeks; from this time it grew gradually ſmaller. Kepler ſuppoſes that it diſappeared ſome time between October, 1605, and the February following, but on what day is uncertain.

Beſides theſe ſeveral re-apparent ſtars, ſo well characterized and eſtabliſhed by the earlieſt among the modern aſtronomers, there have been many diſcovered ſince, by Caſſini, Maraldi, and others; Mr. Montanere ſpeaks of having obſerved above one hundred changes among the fixed ſtars.

PROPER MOTION OF THE STARS.

Many ſtars have been found to alter their poſition with reſpect to thoſe to which they were adjacent, and this change of poſition has been termed the *proper motion of the ſtars*.

The proper motion of Sirius, Caſtor, Procyon, Pollux, Regulus, Arcturus, and Aquilæ, in 100 years in right aſcenſion, are reſpectively, 1 minute, 3 ſeconds; 1 minute, 28 ſeconds; 1 minute, 33 ſeconds; 41 ſeconds; 2 minutes, 20 ſeconds; and 57 ſeconds. The proper motion of Sirius in declination, in a century, is 2 minutes; and of Arcturus is 3 minutes, 21 ſeconds, both tending to the ſouth.

The apparent brightneſs of ſome of the fixed ſtars is obſerved to be periodic. The ſtar Algol, in

in Medusa's head, has been observed long since to appear of different magnitudes, at different times. The period of it has been lately settled by J. Goodrick, Esq. of York. It periodically changes from the first to the fourth magnitude; the time employed from one greatest diminution to the other, was, anno 1783, at a mean 2 days, 20 hours, 49 minutes, 3 seconds. The changes are thus: during four hours it gradually diminishes in lustre; during the succeeding four hours, it recovers it's first magnitude by a like gradual increase; and during the remaining part of the period, namely, 2 days, 12 hours, 49 minutes, 3 seconds, it invariably preserves it's greatest lustre; after the expiration of which term, the diminution again commences.

The causes of these appearances cannot be assigned at present, with any degree of probability; perhaps they have some analogy to the spots on the sun, which at some times appear in greater numbers than at others, some of them bigger than the whole earth; or perhaps they are owing to some real motions of the stars themselves.

There are several stars that appear single to the naked eye, which are, on examination with a telescope, found to consist of two, three, &c. The number of double stars observed before the time of Dr. Herschel, was but small; but this celebrated astronomer has noted upwards of four hundred; among these, some that are double, others that are treble, double double, quadruple, double treble, and multiple; his catalogue gives the comparative size of these stars, their colour as they appeared to him, with several other very curious particulars.

HERSCHEL ON THE CONSTRUCTION OF THE UNIVERSE.

Before I leave the subject of the fixed stars, I shall endeavour to give you an account of Dr. Herschel's

Herſchel's ideas of the conſtruction of the univerſe. Former aſtronomers had ſuppoſed, that our ſun, beſides occupying the center of his own ſyſtem, was alſo the center of the univerſe; and that the ſiderial heavens might be properly repreſented on the concave ſurface of a ſphere: but theſe are ill adapted, ſays the Doctor, for a delineation of the interior parts of the heavens. Being able to penetrate into theſe regions by means of large teleſcopes,* we may now conſider them as a naturaliſt regards a rich extent of ground, or a chain of mountains, containing *ſtrata* variouſly *inclined* and *directed*, and compoſed of very different materials. He gives ſtrong reaſons, deduced from a ſeries of obſervations, as well as conſiderations drawn from analogy, to prove that the viſible ſyſtem of nature, which we call *the univerſe*, conſiſting of all the celeſtial bodies, and many more than can be ſeen by the naked eye, is only a group of ſtars, or ſuns, with their planets, conſtituting one of thoſe patches called a nebula; and this is, perhaps, not one ten thouſandth part of the univerſe.

Dr. Herſchel found that his large teleſcope completely reſolved the whitiſh appearance of the Via Lactea into ſtars. Having viewed and guaged this bright zone in all directions, he found it compoſed of ſhining ſtars, whoſe number conſtantly increaſes and diminiſhes, in proportion to it's apparent brightneſs to the naked eye. There is, ſays he, no doubt but that the milky way is a moſt extenſive ſtratum of ſtars of various ſizes, and that our ſun is one of the heavenly bodies belonging to it.

The portion of the milky way that he firſt obſerved, was that about the hand and club of Orion;

* Dr. Herſchel's obſervations, on which this theory is founded, were made with a Newtonian reflector, of 20 feet focal length, and an aperture of 18 inches.

Orion; here he found an aſtoniſhing multitude of ſtars, which he attempted to number; by eſtimating the number contained in the field of his teleſcope at once, and computing from a mean of theſe, how many might be contained in a given portion of the milky way, in the moſt vacant places about that part, he found 63 ſtars; other ſix fields contained 110, 60, 70, 90, 70, and 74 ſtars; a mean of theſe gives 79 for the number of ſtars in each field: ſo that allowing 15 minutes for the diameter of his field of view, a belt of 15 degrees long, and 2 degrees broad, could not contain leſs than 50,000 ſtars, large enough to be diſtinctly numbered; beſides which, he ſuſpected twice as many more, which could be ſeen only now and then by faint glimpſes, for want of ſufficient light.

It is very probable, that the great ſtratum, called the *milky way*, is that in which the ſun is placed, though not in the very center of it's thickneſs. This is gathered partly from the appearance of the galaxy, which ſeems to encompaſs the whole heavens, as it certainly muſt do, if the ſun is within the ſame. For, ſuppoſe a number of ſtars arranged between two parallel planes, infinitely extended every way, but at a given conſiderable diſtance from each other, and calling this a *ſiderial ſtratum*, an eye placed ſomewhere within it, will ſee all the ſtars in the direction of the planes of the ſtratum projected into a great circle, which will appear lucid on account of the accumulation of the ſtars; while the reſt of the heavens, at the ſides, will only ſeem to be ſcattered over with conſtellations, more or leſs crowded, according to the diſtance of the planes, or numbers of the ſtars, contained in the thickneſs or ſides of the ſtratum.

If the eye were placed without the ſtratum, but at no very great diſtance, the appearance of the

the ſtars within it would aſſume the form of one of the leſſer circles of the ſphere: which would be more or leſs contracted, according to the diſtance of the eye: if this was exceedingly increaſed, the whole ſtratum might at laſt be drawn into a lucid ſpot of any ſhape, according to the poſition, length, and height of the ſtratum. What has been inſtanced in parallel planes, may be eaſily applied to ſtrata irregularly bounded, and running in various directions; and thus any kind of curvatures, as well as various degrees of brightneſs, may be produced in the projection.

From appearances, he infers that the ſun is placed in one of the great ſtrata of the fixed ſtars, and very probably not far from the place where ſome ſmaller ſtratum branches out from it. Such a ſuppoſition accounts for all the phenomena of the milky way with great eaſe and ſimplicity, while every ſtar in the ſtratum will have it's own galaxy, with only ſuch variations in form and luſtre, as may ariſe from their particular ſituation.

There is, ſays Dr. Herſchel, a remarkable clearneſs and purity in the heavens, when we look out of our ſtratum at the ſides, that is, towards Leo, Virgo, and Coma Berenices, on one ſide, and towards Cetus on the other; whereas the ground of the heavens becomes troubled, as we approach towards the length or height of it. Theſe troubled appearances are eaſily to be explained, by aſcribing them to ſome of the diſtant ſtraggling ſtars, that hardly yield light enough to be diſtinguiſhed; but when we look towards the pole of our ſyſtem, where the viſual ray does not graze along the ſide, the ſtraggling ſtars of courſe will be very few in number, and therefore the ground of the heavens will appear much purer and more clear.

Dr. Herſchel points out the methods whereby the ſun's place in the ſiderial ſtratum may be aſcertained,

aſcertained, but theſe demand more previous knowledge than is neceſſary in an introductory Lecture like the preſent. After this, he lays down ſome ſuppoſitions on the ſubject, taking a point of view at a very remote period of time, and an immenſe diſtance of ſpace; theſe for the ſame reaſon we ſhall leave untouched, and proceed to his view of the heavens from our own retired ſtation, in one of the planets, attending to a ſtar in it's great combination with numberleſs others; and in order to inveſtigate what will be the appearances from this contracted ſituation, let us begin with the naked eye.

The ſtars of the firſt magnitude, being in all probability the neareſt, will furniſh us with a ſtep to begin the ſcale. Setting off, therefore, with the diſtance of Sirius or Arcturus, for inſtance, as unity, we ſhall at preſent ſuppoſe, that thoſe of the ſecond magnitude are at double, thoſe of the third at treble the diſtance, &c. Taking it for granted, then, that a ſtar of the ſeventh magnitude (the ſmalleſt viſible to the naked eye) is about ſeven times as far as one of the firſt, it follows, that an obſerver who is incloſed in a globular cluſter of ſtars, and not far from the center, will never be able, by his naked eye, to ſee to the end of it; for ſince, according to the foregoing eſtimations, he can only extend his view to about ſeven times the diſtance of Sirius, it cannot be expected that his eyes ſhould reach the borders of a cluſter, which has perhaps no leſs than 50 ſtars in depth every where around him. The whole univerſe therefore, to an obſerver confined to unaſſiſted viſion, will be comprized in a ſet of conſtellations richly ornamented with ſcattered ſtars of all ſizes. Or, if the united brightneſs of a neighbouring cluſter of ſtars ſhould, in a remarkably clear night, reach his ſight, it will

put

put on the appearance of a ſmall, faint, whitiſh nebulous cloud, not to be perceived without the greateſt attention. Let us ſuppoſe him placed in a much extended ſtratum, or branching cluſter of millions of ſtars: here the heavens will not only be richly ſcattered over with brilliant conſtellations, but a ſhining zone or milky way will be perceived to ſurround the whole ſphere of the heavens, owing to the combined light of the ſtars that are too remote to be ſeen; our obſerver's ſight will be ſo confined, that he will imagine this ſingle collection of ſtars, though he does not perceive the thouſandth part of them, to be the whole contents of the heavens. Allowing him now the uſe of a common teleſcope, he begins to ſuſpect that all the milkineſs of the bright path, which ſurrounds the ſphere, may be owing to ſtars: he perceives a few cluſters of them in various parts of the heavens, and finds alſo that there is a kind of nebulous patches; but ſtill his views are not extended to reach ſo far as to the end of the ſtratum in which he is ſituated; ſo that he looks upon theſe patches as belonging to that ſyſtem which, to him, ſeems to comprehend every celeſtial object. He now increaſes his power of viſion, and applying himſelf to a cloſer obſervation, finds that the milky way is indeed no other than a collection of very ſmall ſtars: he perceives that thoſe objects, which had been called nebulæ, are evidently nothing but cluſters of ſtars; their number increaſes upon him; and whilſt he reſolves one nebula into ſtars, he diſcovers ten new ones that he cannot reſolve. He then forms the idea of immenſe ſtrata of fixed ſtars, of cluſters of ſtars, and of nebulæ, till going on with ſuch intereſting obſervations, he ſoon finds that all theſe appearances ariſe from the confined ſituation in which we are placed. *Confined* it may be juſtly

ly called, though contained in no ſmaller a ſpace than what appeared before to be the whole region of fixed ſtars, but which now has aſſumed the ſhape of a crookedly branching nebula; not one of the leaſt, but probably very far from being the moſt conſiderable, of thoſe numberleſs cluſters that enter into the conſtruction of the heavens. Dr. Herſchel confirms theſe ideas by a ſeries of obſervations, and thinks it will be found upon the whole, that this view, with all it's conſequential appearances, as ſeen by an eye incloſed in one of the nebulæ, is no other than a drawing from nature, wherein the features of the original have been cloſely copied; and Dr. Herſchel hopes the reſemblance will not be called a bad one, when it ſhall be conſidered how very limited muſt be the pencil of an inhabitant of ſo ſmall and retired a ſpot of an indefinite ſyſtem, in attempting the picture of ſo unbounded an extent.

In the moſt crouded parts of the milky way, he has had a field of view of 588 ſtars, and theſe continued for many minutes; ſo that in one quarter of an hour's time, not leſs than 116,000 ſtars have paſſed through the field of his teleſcope: he endeavours to ſhew, that the powers of his teleſcope are ſuch, that it will not only reach the ſtars at 497 times the diſtance of Sirius, ſo as to diſtinguiſh them, but that it alſo ſhews the united luſtre of the accumulated ſtars that compoſe a milky nebuloſity at a far greater diſtance. From theſe conſiderations, it is highly probable, that as his 20 feet teleſcope does not ſhew ſuch a nebuloſity in the milky way, it goes already far beyond it's extent; and therefore a more powerful inſtrument would remove all doubt, by expoſing a milky nebuloſity beyond the ſtratum, which could then no longer be miſtaken for the dark ground of the heavens.

To the foregoing arguments, we may add the following, drawn from analogy. Dr. Herſchel ſays, that among the great number of *nebulæ* which he has already ſeen, amounting to more than 900, there are many, in all probability, equally extenſive with that which we inhabit; and yet they are all ſeparated from each other by very conſiderable intervals. Some, indeed, there are, that ſeem to be double and treble; and though with moſt of them it may be, that they are at a very great diſtance from each other, yet he does not mean to ſay that there are no ſuch conjunctions; though there may be alſo ſome thinly ſcattered ſolitary ſtars, not yet drawn into ſyſtems; their number cannot be very conſiderable: a conjecture that is abundantly confirmed, in ſituations where the nebulæ are near enough to have their ſtars viſible; for they are all inſulated, and generally to be ſeen upon a very clear and pure ground, without any ſtar near them, that might be ſuppoſed to belong to them: and though they may be often ſeen in beds of ſtars, yet from the ſize of theſe ſtars, we may be certain that they are much nearer to us than thoſe nebulæ, and belong undoubtedly to our own ſyſtem.

THE ORIGIN OF NEBULOUS STRATA.

Dr. Herſchel thinks the nebula that we inhabit, has fewer marks of profound antiquity upon it than the reſt; having previouſly ſuppoſed that the condenſation of cluſters of ſtars is to be aſcribed to a gradual approach; the number of ages that muſt have paſt before ſome of the cluſters could be ſo far condenſed as they are at preſent, makes him naturally aſcribe a certain air of youth and vigour to many very regularly ſcattered regions of our ſiderial ſyſtem. There are many places, where he aſſerts that there is reaſon to believe, that the ſtars,

if we may judge from appearances, are now drawing towards various fecondary centers, and will, in time, feparate into different clufters, fo as to occafion many fub-divifions. Our fyftem, after numbers of ages, may be divided fo, as to give rife to a ftratum of two or three hundred nebulæ.

An Opening in the Heavens.

Some parts of our fyftem feem to have already fuftained greater ravages from time than others: in the body of the Scorpion, there is an opening, or hole, which is probably owing to this caufe; it is 4 degrees broad.

A perforated Nebula, or Ring of Stars.

Among the curiofities of the heavens, fhould be placed a nebula that has a regular concentric dark fpot in the middle, and is probably a ring of ftars; it is of an oval fhape; in the northern fide 3 very faint ftars may be feen, as alfo one or two in the fouthern: the vertices of the longer axis feem lefs bright, and not fo well defined as the reft.

Planetary Nebulæ.

Thefe are fo named from a fingularity of appearance, which renders it difficult to clafs them. Their light is fo uniform and vivid, the diameters fo fmall and well defined, as make it improbable that they fhould be common nebulæ: if nebulæ, they muft be compreffed, and condenfed in the higheft degree.

Though the words *condenfation* and *clufter* often occur in the foregoing extract, we are by no means to infer that any of the celeftial bodies, in

our nebula, are nearer to one another than we are to Sirius, whoſe diſtance is ſuppoſed to be not leſs than 38 millions of miles. The whole extent of the nebula being, in ſome places, near 500 times this diſtance, muſt be ſuch, that the light of a ſtar placed at it's extreme boundary, ſuppoſing it to fly with the velocity of 12 millions of miles every minute, muſt have taken near 3000 years before it could reach us.

These immenſe ſpaces, theſe numerous hoſts of ſyſtematic univerſes, are probably connected the one with the other. Like ſo many immenſe circuſes, by the mutual contact of their circumambient ſpheres, they preſs each other: theſe aereal atmoſpheres being alſo connected and interwoven together by an infinity of inſertions, conſtitute a celeſtial ſphere, which is again linked with others, till by an infinity of orbs they obtain a form, which is the origin and pattern of all forms, in which all the variegated ſiderial revolutions harmoniouſly concur to one and the ſame end; that of mutually ſtrengthening and eſtabliſhing each other, and forming a celeſtial union.

OF THE TELESCOPIC APPEARANCE OF THE PLANETS.

OF THE SUN.

"The obſervations which might with fullneſs of evidence confirm the opinion of planetary worlds, ſeem to be placed out of our reach, and we can ſcarce hope to make our optical inſtruments ſufficiently perfect, to render the inhabitants thereof viſible to us. All, therefore, that we can do, is to examine if the planets are accommodated with thoſe things which we are uſed to conſider as neceſſary to animal exiſtence. Lands, ſeas, clouds, vapours,

vapours, and an atmoſphere, or body of air, are objects that we may expect to find on the face of an habitable world."

By means of the teleſcope, we are enabled, in ſome meaſure, to aſcend into the celeſtial region, and view the ſun, moon, and ſtars, as they would appear to us if they were brought ſo many times nearer to us as the teleſcope magnifies; the light proceeding from the luminary we are looking at, being diminiſhed in the ſame proportion.

The teleſcope is one of thoſe diſcoveries, of which no idea could have been formed, previous to the period in which the *Supreme Being* was pleaſed to unveil to the human mind ſome of the myſterious powers of glaſs: the importance of this diſcovery, and the extent to which it may be carried, ſtill lie hid among the ſecrets of infinite wiſdom. It is by this inſtrument more than by any other, that we have been led onward in our advances towards a perfect knowledge of the heavenly bodies, and that aſtronomy has been raiſed from little more than a catalogue of ſtars, into a ſcience.

When we look at the ſun through a teleſcope even of moderate power, the eye being defended by a piece of coloured or ſmoked glaſs, nay, even by the naked eye, when guarded in the ſame manner, we diſcover on his ſurface many black, or rather leſs bright ſpots, of various ſizes and ſhapes. Sometimes theſe ſpots will vaniſh in a very ſhort time after their firſt appearance; ſometimes they travel over his whole diſk, or viſible ſurface, from weſt to eaſt, when they diſappear, and in twelve or thirteen days they appear again, ſo as to be known, by their magnitude and figure, to be thoſe that had diſappeared before. Thoſe, however, which are of the longeſt continuance, do not appear to have much ſolidity of conſiſtence, for in a little time

they alſo vaniſh, and become bright like the reſt of the ſurface.

The ſpots are more frequent at ſome periods than at others; in ſome years, the ſun's diſk has for many months been perfectly free from them; in others, he has for months been more or leſs obſcured by ſpots: the moſt remarkable phenomena of theſe ſpots, as obſerved by Schenier and Hevelius, are as follow: 1. Every ſpot, which has a nucleus, or dark part, hath alſo an umbra, or fainter ſhade, ſurrounding it. 2. The boundary betwixt the nucleus and umbra is always diſtinct and well-defined. 3. The increaſe of a ſpot is gradual, the breadth of the nucleus and umbra dilating at the ſame time. 4. In like manner, the decreaſe of a ſpot is gradual, the breadth of the nucleus and umbra diminiſhing at the ſame time. 5. The exterior boundary of the umbra never conſiſts of ſharp angles, but is always curvilinear, how irregular ſoever the outſide of the nucleus may be. 6. The nucleus of a ſpot, whilſt on the decreaſe, often changes it's figure, by the umbra incroaching irregularly upon it, inſomuch that in a ſmall ſpace of time new incroachments are diſcernable, whereby the boundary between the nucleus and the umbra is perpetually varying. 7. It often happens, that by theſe incroachments the nucleus of a ſpot is divided into two or more nuclei. 8. The nuclei of the ſpots vaniſh before the umbra. 9. Small umbræ are often ſeen without nuclei. 10. A large umbra is ſeldom ſeen without a nucleus in the middle of it. 11. When a ſpot, which conſiſted of a nucleus and an umbra, is about to diſappear, if it be not ſucceeded by a facula, or ſpot, brighter than the reſt of the diſk, the place it occupied is in a very little time not to be perceived.

In the Philoſ. Tranſ. vol. lxiv. the reader will find ſeveral curious obſervations on theſe ſpots, by Profeſſor Wilſon, and the Rev. Mr. Wolaſton. The latter

latter gentleman ſays, he once ſaw, with a twelve-inch reflector, a ſpot burſt to pieces, while he was looking at the ſun; the appearance was to him as that of a piece of ice, when daſhed on a frozen pond, which breaks to pieces, and ſlides in various directions.

The ſpots are by no means confined to one part of the ſun's diſk, though we do not know that any have been obſerved about his polar regions. Though their direction is from eaſt to weſt, yet the paths they deſcribe in their courſe over the diſk, are exceedingly different, ſometimes being in ſtrait lines, ſometimes in curves; at one time deſcending from the northern to the ſouthern part of the diſk, at other times aſcending from the ſouthern to the northern part.

The larger ſpots, moſt of which exceed the whole earth in apparent magnitude, laſt a conſiderable time, ſometimes three months before they diſappear, at which time they are generally converted into ſpots exceeding the reſt of the ſun in brightneſs. The general opinion concerning their nature is, that they are volcanoes, or burning mountains of immenſe ſize; and that when the eruption is nearly ended, and the ſmoke diſſipated, the fierce flames are expoſed, and appear as luminous ſpots. D. Wilſon ſuppoſes them, on the other hand, to be excavations in the luminous matter (or atmoſphere) that environs the body of the ſun.

The diameter of a ſpot near the middle of the diſk, is meaſured by comparing the time it takes in paſſing over a croſs hair in a teleſcope, with the time wherein the whole diſk of the ſun paſſes over the ſame hair. It may alſo be meaſured by a micrometer. Hevelius obſerved a ſpot that roſe, and vaniſhed, in 16 or 17 hours. None have been obſerved to continue longer than 70 days.

OF THE MOON.

When we look at *the moon* with the naked eye, we difcern a great number of irregular fpots on her difk, diftinguifhed by their dark colour from the brighter or more glaring parts; but when viewed through a telefcope, their number is prodigioufly increafed; and it is perceived, that many of thefe appearances are occafioned by vaft obfcure pits or cavities, and elevations or mountains. The fpots in the moon always keep their places, not being moveable like thofe of the fun. Sometimes more or lefs, of the northern, and fouthern, and eaftern, and weftern, part of the difk is feen, which is owing to what is called her libration.

Thefe mountains and cavities are known to be fuch, from the fhadow they caft. In the firft and fecond quarters, when the light of the fun falls obliquely upon them, the elevated parts caft a triangular fhadow on the fide oppofite to the fun; whereas, with refpect to the cavities, thefe have that fide which is oppofite to the fun illuminated, and that which is next the fun is dark and obfcure, the fame as would happen to a hollow bafon, placed on a table at fome diftance from a candle, in a room where there is no other light. The fhadows fhorten as the fun becomes more directly oppofed to the anterior face of the moon, and at length difappear at the time of the full. During the third and laft quarters, the fhadows appear again, but all fall towards the contrary fide of the moon, though ftill with the fame diftinction, namely, that the mountains are dark and fhady on the fide fartheft from the fun, and the pits are dark on the fide next the fun.

The full moon is a very pleafing fight through a telefcope, and has a great variety of luftre and colour;

colour; but it is not the face on which to diſcover the mountains, theſe are beſt ſeen at the increaſe or decreaſe; for beſides the evidence derived from the ſhadows, we may then ſee the tops of theſe mountains catching the rays of the ſun before they reach that part of the ſurface on which their bottoms are placed.

On April 19, 1787, Dr. Herſchel obſerved ſome appearances on the ſurface of the moon, which, judging by analogy from things perceived here with us, he thought he might term *volcanoes*. Three of theſe he obſerved in different places of the dark part of the moon; two of them appeared nearly extinct, or going to break out; the third, as an actual eruption of fire, or luminous matter. On the 20th it burnt with greater violence, and might be computed to be about three miles in diameter: the eruption reſembled a piece of burning charcoal, covered by a thin coat of white aſhes; all the adjacent parts of the volcanic mountain were faintly illuminated by the eruption, and were gradually more obſcure as they lay at a greater diſtance from the crater. Dr. Herſchel had, in 1783, obſerved an eruption, ſomewhat ſimilar to that of the foregoing volcano. Indeed an appearance of this kind had been ſeen before, by Don Ulloa, in an eclipſe of the ſun. It was a ſmall bright ſpot, near the margin of the moon, which he ſuppoſed to be a hole with the ſun's light ſhining through it.

That the moon is ſurrounded by an atmoſphere, is rendered probable by many obſervations of the ſolar eclipſes, in which the edge or limb of the ſun was obſerved to tremble juſt before the beginning. The planets are likewiſe obſerved to change their figure from round to oval, juſt before the beginning of an occultation behind the moon, which can be attributed to no

other cauſe than that their light is refracted by being ſeen through the moon's atmoſphere. That we ſee no clouds, will not appear ſurprizing, if we conſider that the lunar days and nights are thirty times as long as our's; it will be eaſy to conceive, that with them the phenomena of vapours may be very different from what they are with us; perhaps their clouds and rain, if any, may be condenſed into viſible quantities only during the abſence of the ſun, and of courſe when they muſt be inviſible to us.

Mercury being at all times near the ſun, we can only diſtinguiſh by the teleſcope a variation of his figure, which is ſometimes that of a half moon, ſometimes a little more or leſs than half.

Venus, when in the form of a creſcent, and at her brighteſt times, affords a more pleaſing teleſcopic view than any other of the heavenly bodies; her ſurface is diverſified with ſpots, like thoſe of the moon; by the motion of theſe, the time ſhe takes up in revolving upon her axis is diſcovered. With a powerful teleſcope, mountains like thoſe in the moon may be ſeen.

Mars appears always round and full, except at the time of the quadrature, when it's diſk appears like that of the moon about three days after the full. By the ſpots which are ſeen on it's ſurface, it's diurnal revolution has been aſcertained. From it's characteriſtic ruddineſs, and from other phenomena, it has been ſuppoſed that it's atmoſphere is nearly of the ſame denſity with our's. Dr. Herſchel has obſerved two white luminous circles ſurrounding the poles of this planet; theſe are ſuppoſed to ariſe from the ſnow lying about thoſe parts.

The appearance of *Jupiter* through a teleſcope, opens a vaſt field for ſpeculative inquiry. The ſurface is not equally bright, but is diſtinguiſhed

guifhed by certain bands, or belts, of a dufkier colour than the reft of the furface, running parallel to each other, and to the plane of it's orbit. They are not regular or conftant in their appearance; fometimes only one is feen, at other times eight have been feen; their breadth is likewife variable, one belt growing narrow while another in it's neighbourhood becomes broader, as if one had flowed into the other; in this cafe an oblique belt has been obferved to lie between them, as if for the purpofe of forming a communication. Sometimes one or more fpots are formed between the belts, which increafe till the whole is united in one large dufky band. There are alfo bright fpots to be difcovered on Jupiter's furface; thefe are rather more permanent than the belts, and re-appear after unequal intervals of time. The remarkable fpot, by whofe motion the rotation of Jupiter on his axis was afcertained, difappeared in 1694, and was not feen again till 1708, when it re-appeared exactly in the fame place, and has been occafionally feen ever fince. The difappearance and re-appearing of the fpots is not fo wonderful as the changes that have been obferved in the belts; the elder Caffini faw one evening five belts upon the planet, but while he was viewing them, they underwent the moft furprizing change. In an hour from their fulleft appearance there remained only three out of five, and one of thefe fcarce perceptible. The moft remarkable telefcopic appearance of this planet, are the fatellites, but thefe I have particularly defcribed under the head of *fatellites*.

Though the great diftance of the planet *Saturn*, and the tenuity of it's light, do not permit us to diftinguifh the varieties of it's furface; yet fome of the firft difcoveries made by the telefcope were on this planet, and the ring is ftill one of

of the moſt curious phenomena we are acquainted with. There is not, indeed, any thing in the whole ſyſtem of nature more wonderful than this ring, which appears nearly as bright as any part of the ſurface of the planet: by what means it is ſuſpended, or by what law ſupported; whether it is only a bright but permanent cloud, or whether it is a vaſt number of ſatellites diſpoſed in the ſame plane, whoſe blended light gives it to us the form of one continual body, we can only form crude conjecture. M. Meſſier has obſerved on the anſes of this ring, ſeveral luminous white twinkling points, differing in vivacity from each other.

Sometimes our eye is in the plane of the ring, and then it becomes inviſible: as it's plane always keeps parallel to itſelf, it diſappears twice in every revolution of the planet, that is, about once in 15 years; and he ſometimes appears quite round for nine months together. At other times the diſtance betwixt the body of the planet and the ring is very perceptible, inſomuch that Dr. Clarke's father ſaw a ſtar through the opening. When Saturn appears round, if our eye be in the plane of the ring, it will appear as a dark line acroſs the middle of the planet's diſk; if the eye be elevated above the plane, a ſhadowy belt will be viſible; when the plane appears, the ring next the body is the brighteſt; when the ring appears of an elliptical form, the parts about the ends of the largeſt axis are called anſæ. Theſe, a little before and after the diſappearing of the ring, are of unequal magnitude. It has been ſuppoſed, that the ring has a rotation round an axis.

With very long teleſcopes two belts have been diſcovered on Saturn, which appear parallel to that formed by the edge of the ring; theſe are ſaid to be permanent: Caſſini and Fatio perceived a bright

a bright ſtreak upon Saturn which was not permanent, being viſible one day, diſappearing the next, when another came into view near the edge of his diſk. Beſides theſe there are it's five ſatellites mentioned under their proper head.

OF COMETS.

Comets are a kind of ſtars, appearing at unexpected times in the heavens, and of ſingular and various figures, deſcending from far diſtant parts of the ſyſtem, with great rapidity, ſurpriſing us with the ſingular appearance of a train, or tail; and after a ſhort ſtay, are carried off to diſtant regions, and diſappear.

They were imagined in ancient times to be prodigies hung out by the immediate hand of GOD in the heavens, and intended to alarm the world. Their nature being now better underſtood, they are no longer terrible. But as there are ſtill many who think them to be heavenly warnings, portents of future events, it may not be improper to inform you, that the *Architect* of the univerſe has framed every part according to divine order, and ſubjected all things to laws and regulations; that he does not hurl at random ſtars and worlds, and diſorder the ſyſtem of the whole glorious frame, to produce falſe apprehenſions of diſtant events, fears without foundation, and without uſe. *Religion* glories in the teſt of reaſon, of knowledge, and of true wiſdom; it is every way connected with, and is always elucidated by them. From philoſophy we may learn, that the more the works of the *Lord* are underſtood, the more he muſt be adored; and that his ſuperintendancy over every portion is more clearly evinced, and more fully

fully expreffed by their unvaried courfe, than by ten thoufand diviations.

The exiftence of an univerfal connection between all the parts of nature is now generally allowed. Comets undoubtedly form a part of this great chain; but of the part they occupy, and of the ufes for which they exift, we are equally ignorant. It is a portion of fcience whofe perfection is referved for fome diftant day, when thefe bodies and their vaft orbits may, by long and accurate obfervation, be added to the known parts of the folar fyftem; when aftronomy will appear as a new fcience, after all our difcoveries, great as we at prefent imagine them to be.

The aftronomy of comets is very imperfect; for but little can be known with certainty, where but little can be feen. Comets afford few obfervations on which to ground conjecture, and are for the greateft part of their courfe beyond the reach of human vifion; but that they are not meteors in the air is plain, becaufe they rife and fet in the fame manner as the moon and ftars; they are called comets, from their having a long tail fomewhat refembling the appearance of hair; fome however have appeared without this appendage, as well defined and round as planets.

It is generally fuppofed, that they are planetary bodies, making part of our fyftem, revolving round the fun in extremely long elliptic curves; that as the orbit of a comet is more or lefs excentric, the diftance to which they recede from the fun will be greater or lefs. Very great difference has been found by obfervation in this refpect, even fo great, that the fides of the elliptic orbit in fome cafes degenerate almoft into right lines. They are very numerous: 450 are fuppofed to belong to our folar fyftem.

Thefe comets, which go to the greateft diftance

diſtance from the ſun, approach the neareſt to him at their return.

Their motion in the heavens are not all direct, or according to the order of the ſigns, like thoſe of the other planets. The number of thoſe which move in a retrograde manner, is nearly equal to thoſe whoſe motion is direct.

The orbits of moſt of them are inclined in very large angles to the plane of the ecliptic.

The velocity with which they move is variable in every part of their orbit; when they are near the ſun, they move with incredible ſwiftneſs; when very remote from him, their motion is inconceivably ſlow.

When they appear, they come in a direct line towards the ſun, as if they were going to fall into his body: and after having diſappeared for ſome time, in conſequence of his extreme brightneſs, they fly off on the other ſide as faſt as they came, continually loſing their ſplendor, till at laſt they totally diſappear. Their apparent magnitude is very different, ſometimes ſeeming not bigger than the fixed ſtars, at other times equal in diameter to Venus. Hevelius obſerved one in 1652, which was not inferior to the moon in ſize, though not ſo bright; it's light pale and dim, it's aſpect diſmal.

A greater number of comets are ſeen in the hemiſphere towards the ſun, than in the oppoſite; and are generally inviſible at a ſmaller diſtance than that of Jupiter. Mr. Brydone obſerved one at Palmero, in July 1770, which, in 24 hours, deſcribed an arch in the heavens upwards of 50 degrees in length; ſo that if it was far diſtant from the ſun, it muſt have moved at the rate of upwards of 60 millions of miles in a day.

They differ alſo in form from the other planets, conſiſting of a large internal body, which ſhines with

with the reflected light of the ſun, and is encompaſſed with a very large atmoſphere, apparently of a finer matter, much reſembling that of the aurora borealis; this is called the head of the comet, and the internal part the nucleus. When a comet arrives at a certain diſtance from the ſun, an exhalation ariſes from it, which is called the tail.

The tail is always directed to that part of the heavens which is directly or nearly oppoſite to the ſun, and is greater, and brighter, after the comet has paſſed it's perihelium, than in it's approach to it; being greateſt of all when it has juſt paſt the perihelium. The tail of the comet of 1680 was of a prodigious ſize, extending from the head to a diſtance ſcarcely inferior to that of the ſun from the earth.

No ſatisfactory knowledge has been acquired concerning the cauſe of that train of light which accompanies the comets. Some philoſophers imagine, that it is the rarer atmoſphere of the comet impelled by the ſun's rays. Others, that it is the atmoſphere of the comet, riſing in the ſolar atmoſphere by it's ſpecific levity; while others imagine that it is a phenomenon of the ſame kind with the aurora borealis; and that this earth would appear like a comet to a ſpectator placed in another planet.

The number of the comets is certainly very great, conſiderably beyond any eſtimation that might be made from the obſervations we now poſſeſs.

There are,* who do not think the preſent aſtronomy of comets well eſtabliſhed; and that as ſo many ſmall ones are frequently ſeen, they think that nothing can be determined with certainty, till ſome better marks are diſcovered for diſtinguiſhing

* Encyclopædia Britannica, vol. 2. p. 765. Second Edition.

guiſhing one from another, than any at preſent known; and that even the accompliſhment of Dr. Halley's prediction is uncertain: for it is very ſingular, that out of four years, in which three comets appeared, the only one, in which no comet was to be ſeen, ſhould be that very year in which the greateſt aſtronomers that ever exiſted had foretold the appearance of one; and in accounting for it's non-appearance, Mr. Clairault would have been equally ſupported by cometic evidence;* whether he concluded the comet to have been retarded or accelerated by the action of Jupiter and Saturn: a comet appeared in 1757, as well as in 1755, and had he determined the retardation of the comet to be twice as great as he did, another appeared in 1760 to have verified his calculations.

Of a Plurality of Worlds.

The fixed ſtars are generally ſuppoſed to be of the ſame nature with our ſun, each of them attended by planets, which are inhabited by rational creatures like this earth.

Inſtead, therefore, of one ſun, and one world, we find that the region of unbounded ſpace is peopled with ſuns, and ſtars, and worlds. This opinion has been held and taught by many of the moſt celebrated philoſophers and aſtronomers, both in ancient and modern times: in this view of things, our ſyſtem reſembles a ſingle individual of ſome one ſpecies of being in outward nature, diverſified from all it's fellow individuals, by differences uneſſential to the kind and ſpecies; but which conſtitute that beauty, which ariſes from uniformity amidſt variety.

That the fixed ſtars are ſuns, ſhining by their own light, is probable, on account of their immenſe diſtance

* There does not indeed ſeem any evidence to prove the identical return of the ſame comet.

diſtance from us; for as it is impoſſible that at theſe diſtances they could be ſeen by any reflection of light from the ſun, it is natural to ſuppoſe them endowed with a power of emitting light from their own bodies. By comparing the apparent diameter of objects at different diſtances, it is clear that our ſun would appear like a ſtar, were he removed to the diſtance at which they are placed; and that therefore it is truly reaſonable to ſuppoſe, that the fixed ſtars are equal, if not ſuperior in magnitude, to that which is the center of our ſyſtem; and that they are made for the ſame purpoſes with the ſun, to beſtow light, heat, and vegetation, on a certain number of planets revolving round them.

Of their immenſe diſtance from us, and the vaſtneſs of the ſpace they occupy, the reader may form ſome idea, when he is told, that numbers amongſt them are at too great a diſtance to be adequately expreſſed by figures, and beyond the reach of admeaſurement; and this will be heightened, if he conſiders that the ſmalleſt of the ſtars viſible to the eye are much more remote than the larger ones, and that the teleſcope diſcovers ſtars which are too diſtant to be perceptible to the naked eye: that the inſtrument, like our eyes, has it's limits; but the extent of the heavens has no bounds.

The fixed ſtars being ſo far removed from, and for the moſt part inviſible to us; it can ſcarcely be conceived by the narroweſt mind, that they form a part of our ſyſtem, or were created only to give a faint glimmering light to the inhabitants of this globe: for one additional moon would have afforded us more light than the whole hoſt of ſtars; ſuch an opinion is unworthy of our reaſon, inadequate to our conceptions of the Deity. It would be alſo abſurd to ſuppoſe, that the author of nature had made ſo many ſuns without planets, to be enlightened by their light, and vivified by their heat; but more ſo,

to imagine ſo many habitable worlds enlightened by ſuns without inhabitants; we may, therefore, ſafely conclude, that all the planets, of every ſyſtem, are inhabited.

This reaſoning is ſtill further ſtrengthened, by conſidering the immenſity of the ſtarry heavens, in which are innumerable hoſts of ſtars, created as the means to ſome great end. From revelation we learn, that the ultimate end of creation is the peopling of heaven with men. Theſe reſplendent ſuns are clearly then the mediums of exiſtence to ſo many earths, and of men upon them, created to be happy eternally with their God, "*the one eternal thirſt to bleſs.*" "Every ſtar is thus the center of a magnificent ſyſtem, attended by a retinue of worlds, irradiated by it's beams, and revolving round by it's active influence." Thus the greatneſs of God is magnified, and the grandeur of his empire made manifeſt. He is not glorified on one earth, or in one world, but in ten thouſand times ten thouſand. "If we could wing our way to the higheſt apparent ſtar, we ſhould there ſee other ſkies expanded, other ſuns that diſtribute their inexhauſtible beams of day; other ſtars, that gild the alternate night, and other (perhaps nobler) ſyſtems eſtabliſhed in unknown profuſion, through the boundleſs dimenſions of ſpace. Nor does the dominion of the Sovereign of all things terminate here; even at the end of this vaſt tour we ſhould find ourſelves advanced no further than the frontiers of creation, the commencement of the great *Jehovah*'s kingdom.*

This mode of reaſoning applies with greater force to the planets of our own ſyſtem, and gains additional ſtrength from other conſiderations. For

who

* Hervey's Meditations.

who would venture to aſſert, that infinite love and conſummate wiſdom had formed ſuch immenſe material maſſes, ſome of which exceed our earth in ſize, convey them in revolutions round the ſun, furniſh them with moons, grant them the alternate changes of night and day, viciſſitudes of ſeaſons, and all this only to emit their ſcanty light on our earth.

Or who that has ſeen any engine, a windmill for inſtance, and who knows the uſe of it, if he travels into another country, and there ſees an engine of the ſame ſort, will not reaſonably conclude that it is deſigned for the ſame purpoſe? So when we know that the uſe of this planet, the earth, is for an habitation of various ſorts of animals, and we ſee other planets at a diſtance from us, ſome bigger, ſome leſs than the earth, moving periodically round, revolving on their axes, and attended with moons; is it not highly reaſonable to conclude, that they are all deſigned for the ſame uſe as this earth is, and that they are habitable worlds like that we live in?

"Who can conceive them
——————— unpoſſeſs'd
By living ſoul, deſert and deſolate,
Only to ſhine, yet ſcarce to contribute
Each orb a gleam of light?"

Or that the *Almighty*, who has not left with us a drop of water unpeopled, who has in every inſtance multiplied the bound of life, ſhould leave ſuch immenſe bodies deſtitute of inhabitants? It is ſurely much more rational to ſuppoſe them the poſſeſſion of human beings, beings formed with capacities for knowing, loving, and ſerving their Almighty Creator; bleſt and provided with every object conducive to their happineſs, and many of them in a far greater ſtate of purity than the inhabitants of our

our earth, and therefore in poſſeſſion of higher degrees of bliſs, and placed in ſituations, furniſhing them with ſcenes of joy, equal to all that poetry can paint, or religion promiſe: all under the direction, indulgence, and protection of infinite wiſdom and goodneſs.*

The more the heavenly bodies excite our aſtoniſhment, from their ſize, their diſtances, the regularity of their motions, or any peculiarity or perfection we diſcover in thoſe attractions by which they ſeem retained in their places, the more clear it is to any reaſoning head that they could not have made themſelves: and that cloſe connection between cauſe and effect, which the farther we ſearch the more clearly we diſcern, though it has ſtaggered the faith of many a celebrated naturaliſt, is itſelf a proof, if he had not ſtopped ſhort of the concluſion, that all theſe muſt have been the contrivance of conſummate wiſdom, and guided by an unerring hand.

Yet at the ſame time he who ſees that every little corner on this earth of our's is replete with animal life, though but one race on it ſeems to be endowed with reaſoning faculties, cannot but be led on to a conjecture at leaſt, that all thoſe vaſt bodies he diſcovers in the heavens may be peopled with their gradations of inhabitants likewiſe; and that each of them not improbably contains it's rational beings too, to acknowledge and adore the Creator of them all. So far the heathen philoſopher may go: though, if he be a modeſt inquirer after truth, he will not dogmatize, or enter into any particular detail of what is ſo totally out of his reach.

But the chriſtian may perhaps allow himſelf, not to dogmatize on his part, but to carry his conjec-

* See the Rev. Mr. Woolaſton's Reflections.

tures a few ſteps farther. Revolving in his mind what he acknowledges has been done for man, the only rational inhabitant he knows on our earth; and conſidering that God has ſent ſome of his angels or meſſengers from time to time to declare his will to us; and has moreover ſent the Chriſt more fully to reveal it; whatever others may think, he is ſatisfied thereby that however ſmall we are in this vaſt univerſe, we are not beneath the notice of the Ruler of it. Loſt in amaze at the greatneſs, and at the ſame time the goodneſs of the Deity towards us, will he not be led thereby into a more full acknowledgment of him, and more determined reſolution of obedience to his will? This ſeems but the rational reſult from ſuch a chain of thought.

Yet, if that thought be purſued, ſince the inhabitants of the other planets of our ſyſtem, and of the many ſyſtems there may be among the numberleſs ſtars in the vaſt expanſe, muſt equally be objects of the Divine favour with ourſelves; and ſince the rational inhabitants of ſome few or more among ſo many myriads, may have been found diſobedient; is a man to blame for thinking that if they ſtand in need of reſtoration, they muſt be full as worthy of it as ourſelves; and may, for any thing that we know, have been already redeemed, or may yet be to be redeemed, when and in what way it ſhall be ſeen fitting by the Almighty Ruler of us all?

LECTURE XLV.

On Physical Astronomy. *

THE caufes of the celeftial motions have in all ages been the objects of philofophical curiofity. Men have generally conducted their refearches on this fubject upon principles of *analogy*. Some refemblances have been noticed between the motions of the celeftial bodies, and other motions nearer at hand, and more familiar to us ; and the fame refemblances have been fuppofed to exift between their caufes.

I fhall notice four of thefe different refemblances, or analogies.

1. The motions of the heavenly bodies have been thought to refemble the fpontaneous motions of *intelligent beings*. Ariftotle, Leibnitz, Tucker, Monboddo, and fome others, both in ancient and modern times, have taught, that the planets were conducted by fpiritual intelligent beings.

Though accounts of the celeftial phenomena may be given by means of this refemblance, that are chargeable with no falfe reafoning ; yet as they afford no explanation, they anfwer no purpofe in philofophy.

2. The celeftial motions have been thought to reprefent the motions of bodies carried about centers by means of *folid connections*.

This notion fuggefted to philofophers the opinion, that the planets were attached to *folid orbs*, which turn round the axis of revolution : this opinion

* Profeffor Robifon's Outlines of Mechanical Philofophy, page 105.

opinion has been falsely attributed to Aristotle. It is altogether contradictory to our ideas of the etherial matter that occupies celestial space, and not easily reconcileable to the elliptic motion of the planets.

3. The celestial motions have been thought to resemble the motions of bodies carried round by a *circulating fluid*. Many philosophers have supposed the planets to be carried round in such vortices. *Descartes* and *Leibnitz* were at great pains to establish this doctrine. More modern writers * have removed the difficulties, and obviated the objections made to this system. It will therefore be necessary to lay before you some of the arguments urged in it's favour; in doing this, I shall be under the necessity of repeating some observations that I have before made.

These writers urge, that so long as we keep within the limits of *natural and experimental philosophy*, we must account for the motions in nature, by referring them to *corporeal* causes; and where this cannot be performed satisfactorily, we must give them up, or wait with patience for some better clue of investigation, or some further light from experience. It is contrary to sound philosophy to amuse ourselves with names and qualities, which contradict the known laws of mechanism, and supersede the operation of the elements.

Nothing is intelligible in philosophy but the action of matter upon matter; the power of impulse is the only sensible and experimental causes of motion; and there is the strongest presumption from analogy in favour of the universal material mechanism of the operations of nature. All other principles of motion are founded on conjecture, and incapable

* Jones's Physiological Disquisitions: Essay on the First Principles of Natural Philosophy; Dr. A. Wilson's Observations on the Moving Powers of the present System.

capable of proof. If you attempt to ſoar above this principle in theory, you are always obliged to deſcend to it in practice. Natural philoſophy has been principally advanced by the experiments which have been made on the *elements*; but *theſe experiments prove, that matter interferes* in producing all the changes and motions that are obſerved in bodies diſtant from each other.

Look into, and obſerve the operations in nature: how does the *ſun act* upon the fruits of the earth, but by the *mediation* of it's *light?* How do the *clouds* water the earth, but by the mediation of *air?* How does the chemiſt produce ſuch wonderful changes in natural bodies, but by the mediation of *fire?* In a word, every experiment, every obſervation proves, that in all caſes where diſtant bodies are found to affect each other, there is always ſomething to mediate, whether we do or do not perceive it; and when this mediation can be no further traced, *natural philoſophy is at an end*, and the fictions of imagination begin, which are of equal value, by whatever name they may be called, or with whatever parade of demonſtration they may be introduced.

It is very ſingular, they obſerve, that inquirers after *phyſical* truth ſhould obſerve and acknowledge mechaniſm in the greater part of nature, and yet not be led thereby to inquire, whether it be not univerſally extended; the more ſo, as matter and motion muſt have the ſame invariable properties. If *vapour riſes* mechanically, why may not *a ſtone deſcend* by the ſame law? If *fluids* circulate in organized bodies by continued impulſe, why may not a *planet* revolve in the organized ſyſtem of the univerſe by the ſame cauſe?

All true philoſophers agree in conſidering the univerſe as a great machine, ſo created, fitted, and diſpoſed by the *power of* God, as to perform all

the operations which are carried on throughout the whole. There is a connection and communication between all the distant parts thereof. No one part can be considered as acting without being acted upon.

It is highly unphilosophical to assert, that matter, considered in general, or any part thereof, has *essential separate qualities*, by which one part acts upon another. It is the essential property of no one wheel in a machine to move it's fellow, though in consequence of it's being placed in the station it is fitted for, it acts upon it's fellow, because it is acted upon. If you interrupt the *contact* in a machine, you destroy the motion in all those parts where the communication is destroyed.

It is just the same with the whole system of nature, you cannot take up any parcel of matter, and say of it, this has essential properties which empower it to be a natural agent. A philosopher ought to consider it as a *concrete*, with a certain disposition of parts liable to be acted upon by the subtiler parts of the machine, which can by no means be restrained by art therefrom. It might be as justly asserted, that it is the essential property of animal substances to *live*, as that it is the essential property of the loadstone to *attract*.

The promoters of the opinion now under consideration, urge further, that every known operation in nature is *mechanical*; and that in all experiments, where the explanation is clear and certain, the effects are produced by matter acting upon matter; and we are able to trace this mechanism in such a variety of instances, that unless the world is governed by opposite and contradictory principles, it must obtain throughout the whole.

Thus the *body of man*, which is the highest piece of machinery in nature, is made to *see*, to *hear*,

hear, and *ſpeak*, upon mechanical principles; and it dies without a conſtant impreſſion of a material force upon it from the element of *air*.

Again, from the preſſure of *air*, the mercury is made to riſe in the tube of the barometer. *Hail*, *ſnow*, and *vapour*, are formed in the atmoſphere by the difference in it's temperature; the clouds are ſuſtained therein, and driven about to water the earth; plants grow, and are nouriſhed thereby.

For thoſe effects where the cauſe is not ſo obvious, you find *fire* a more ſubtil agent, whoſe reality is proved, and it's operations pointed out both by obſervation and experiment. It may be transferred from one parcel of matter to another. It will enter the pores, and fill the interſtitial vacuities of all other ſubſtances. It acts with a force and velocity adequate to all the effects we can deſire to aſcribe thereto. It gives an elaſtic force to air, and occupies every ſpace from which the air is exhauſted. In ſome caſes it acts as *light*, in others as *fire*; light as it illuminates and renders objects viſible, fire as it burns and conſumes what it acts upon.

Thus you find the fluid *etherial matter* of the heavens acting by impulſe on the ſolid matter of the earth, being inſtrumental in every one of it's productions, and neceſſary to every ſtated phenomenon of nature.

We are forced by the evidence of every phenomenon in nature, by every experiment in philoſophy, to conclude, that *impulſe* * is the only material cauſe of motion. All the properties of matter, are ſuch as fit them to act, and to be acted upon, in a mechanical way. They are all ſuch as can

* No mechanical motion can ſubſiſt without a *plenum*; this muſt be, wherever ſuch mechanical motion ſubſiſts. This is ſo neceſſary a conſequence of motion being carried on by impulſe, that it needs no other demonſtration.

can be adapted to the known principles of mechaniſm among artiſts. We are therefore bound by every rule of ſound reaſoning, to conſider it as the cauſe of all the motion, and continuance of motion, in the material univerſe. It is the *one* certain and *only univerſal known cauſe.* Neither the properties of matter, nor experiment, nor obſervation, afford any other.

No *independent motion* can be diſcovered. It is therefore wrong to conſider the motion of any body abſtractedly, or as a thing by itſelf. The ſyſtem of nature is connected and related; and to be underſtood, muſt be conſidered under thoſe relations and connections. Speculations, which carry you out of the world, can never inform you how things are carried on in the world. Matter ſubſiſting as a part of the created world has motion, but if ſeparated from the reſt, would have no more motion than a limb divided from the body; and he who ſtudies the nature of motion by taking matter abſtractedly, is ſtudying motion from that which has no motion belonging thereto.

Another ſtrong argument adduced in favour of this ſyſtem, is derived from the *continuance* and *permanency* of the motions obſerved in nature. That there is an univerſal principle of motion throughout the ſyſtem of things, is ſelf-evident. We know that matter moving, can be the cauſe of motion in matter at reſt; and we know of no other *phyſical cauſe* capable of producing ſuch motion. Here, therefore, we muſt look for the cauſes of permanent motions.

Of the motion in different bodies, it is obſervable, that ſome retain the motion they have acquired, without any diminution, while others are ſoon reduced to a ſtate of reſt. *When a body retains it's motion without diminution,* it is moved by ſuch cauſes as would *renew it's motion, if it were*

were ſtopped. When a *cloud* is flying before the ſun, the ſame wind that drives it on, would reſtore it's motion, if it could be ſtopped. In the ſame manner the *ſails of a wind-mill*, after you have brought them to a ſtate of reſt, and even confined them, will receive a *new* motion from the wind as ſoon as the obſtruction is removed. If you ſtop the motion of the *lungs* by an effort of the muſcles, you find that the natural cauſes that act upon the body, tend to renew the motion, and cannot be hindered from effecting it, without a conſiderable effort.

" *Every laſting motion is ſuch a one therefore, that will be renewed upon it's own principles.* This obſervation is of great importance towards accounting truly for the *undecaying motions* of the univerſe, to all which it may undoubtedly be extended: ſo that if it were poſſible to ſtop the planet Jupiter in his orbit, the *eſtabliſhed cauſes* that act upon him, would renew his motion without any artificial motion.

A body continues to move as long as the natural cauſes of motion continue to act thereon; and *reſt*, which is mechanical *death*, inevitably follows, when the cauſes of motion are no longer preſent. There may be ſubtil caſes, in which it may be as hard for us to trace the cauſes of motion, as to ſhew why life remains for ſome time in an animal body under water without reſpiration. Still, however, the general aſſertion muſt be true, if every effect muſt have it's cauſe; for then to every permanent effect there muſt be a permanent cauſe.

It is therefore not only abſurd, but contrary to every analogy in nature, to ſuppoſe that any of the durable motions of the celeſtial bodies depend upon *projection in a vacuum*: becauſe if you were to ſtop a body moved upon this principle, you have no means of renewing it's motion, it muſt either fall into the ſun, and thus come to a point

point of reſt, or be dead and motionleſs for ever, without ſome miracle to give it a new motion; but this being contrary to the conditions of every undecaying motion, which will be renewed on it's own principles in the ordinary courſe of nature, and by means already eſtabliſhed, is not to be admitted into philoſophy.

They further urge as a reaſon, for rejecting the *hypotheſis* of a *projectile impulſe*, that it obliges it's ſupporters to make the univerſe a *vacuum:* becauſe thoſe *elements* which are ordained to act upon matter, and keep up the life and motion of the world, would ſtand in the way, and hinder the freedom, and diſturb the operation of an imaginary principle, *projection.* They conſider projection not only as an *hypothetical,* but as an *artificial* and *unnatural* principle, that cannot be proved to obtain any where in nature. If it be received, they ſay it muſt be received as an article of *faith.*

Experiments have been made with a *central force machine,* to illuſtrate the doctrine of centripetal and centrifugal forces. But they by no means apply to any caſe in nature, for the moving body is always connected by a line to it's center of motion; a circumſtance that never can be reconciled to motion in a vacuum, where no connection is ſuppoſed, nay, is even objected to upon principle. But theſe experiments are ſtill further deficient, becauſe the *centrifugal* force being a conſequence of, or derived from the artificial revolution of the whirling body, cannot be uſed as a cauſe of the motion: for it is the nature of all cauſes to be *prior* to their effect, but here it is poſterior; the body is never diſpoſed to fly off in a tangent till it has acquired it's revolution. This force can therefore never be applied to account for any of the celeſtial motions, becauſe it brings

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us to this abſurdity, that there is nothing to account for the motion, but the motion itſelf, or the conſequence of the motion.

The ſame objections apply to another illuſtration, namely, caſting round a weight ſuſpended in a ſling, and even further; for the power of the ſling reſtraining the body from flying off in a tangent, bears no analogy to a power actually drawing the moving body towards it's center of motion.

It has been objected to this reaſoning, that no body can move in a ſpace filled with matter, commonly called a *plenum*. But this *entirely depends on the condition of the matter, and the circumſtances of the moving body:* if the matter filling the ſpace be a fluid, whoſe parts can eaſily ſlide over one another, they will be able to move in different or contrary directions at the ſame time, and while the place of the whole maſs remains the ſame, the place of the parts of which it is compoſed, may be continually changing.

The *fullneſs* of the ſpace is therefore no objection to the free motion of the parts of any fluid among themſelves; neither is it any objection to the motion of any ſolid body in ſuch a fluid medium. Though a veſſel be filled with water cloſely ſtopped, (and the fluid ſo compreſſed, that a very ſmall point made to enter therein, would burſt the containing veſſel,) yet any ſolid will move freely therein from one ſide to the other, or from the top to the bottom; becauſe the parts of the fluid which are diſplaced before, fall into that ſpace behind, quitted by the body. So faſt as the body proceeds, juſt ſo faſt do the parts of the fluid recede; ſo that there is *neither impediment nor vacuity*. The ſame is true in other caſes; there may be motion, provided there be a *circulation* among the parts.

When a ſolid body is moved in a fluid by any

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artificial force or violence, *contrary to the nature of the medium in which it moves*, the parts of the medium, by endeavouring to recover their natural ſtate, will reſiſt the motion of the body till the equilibrium is reſtored, and the body is at reſt. Such will neceſſarily be the caſe of all violent motions; it is ſoon deſtroyed by reſiſtance, though the time in which it is deſtroyed may differ from a variety of circumſtances.

But on the other hand, *if the motion of the body ariſes from the motion of the medium in which it moves*, then the reſiſting nature of the medium is no longer an objection to the motion of the body, neither can it be, for it is the *cauſe of it's motion*; and it is abſurd to ſuppoſe, that the cauſe of a motion can reſiſt the motion it cauſes. No inference therefore from the *reſiſtance* of mediums, can lead us to the *neceſſity of a vacuum*. A *vacuum* is only neceſſary when a motion is propoſed, which is *independent* of the action of every medium; but nature knows of no ſuch motion.

A variety of motions may be exhibited, for whoſe production the preſence of a *reſiſting medium* is abſolutely neceſſary; and they ſhew, that ſo far from a *vacuum* being neceſſary to the continuance of motion in any ſpace, the motion is promoted and occaſioned by a reſiſting medium. That *hypothetical* train of reaſoning which leads us to conclude, that if leſs matter were in the ſpace, the motion would be more free, and continue much longer, is as unphiloſophical, as it would be, if in order to enable a man to run faſter, we ſhould rid him of the incumbrance of his boots and ſpurs, by cutting off his legs.

Air is, you know, a *reſiſting medium*, yet inſtead of retarding the motion of the lamp machine,

chine, which I before ſhewed you, by it's reſiſtance preſerves that motion; and if the motion be at laſt diſcontinued, it does not ariſe from defect or irregularity of the cauſe, but to the imperfection of the materials. If the materials which are acted upon would but continue in the ſame ſtate, the motion would be unretarded as long as *air* and *fire*, which are the cauſes thereof, ſubſiſt in the world. In this experiment the cauſes are not *artificial* and *violent*, as in the central force machine, but ſuch as are ſupplied by nature itſelf, in it's regular mode of action; which both *begins* and *continues* the motion. What is performed by the agents in nature, in the one caſe, may certainly be done in others. The *planets* may be carried round in their orbits by the ſame means. The heavens may be filled throughout with an etherial fluid, not infinitely rarified, unreſiſting, and impotent, but denſe and continuous in it's parts.

The writers in favour of the mechanical ſyſtem urge, that their opponents have no notion or means of reſolving their axioms, or relative laws of motion, to mechaniſm, but conſider them merely as laws; another word, as they uſe it, for ultimate, ſpiritual, *unmechanical power*. As the penetration of ſome amongſt them has carried them ſo far as to ſuppoſe an impelling etherial medium for maintaining attraction, gravitation, &c. &c. it is rather ſurpriſing that they could not perceive, that the ſame medium was neceſſary for ſupporting their laws of motion, reſt, reſiſtance, &c. for the difficulty does not lie in accounting for gravitation, or any *particular* kind of motion, but in finding *powers* to produce and maintain motion in general. If theſe are mechanical, it is eaſy to ſuppoſe, that the *contriver* may have adjuſted the mechaniſm ſo as to produce the particular tendencies. But if they are unmechanical,

nical, you may call them laws, properties, or any other name, either with or without a meaning. How detrimental it is to the increafe of knowledge in the powers and agency of nature, to have the moft curious productions of thefe powers reduced to *unintelligible* laws, characterized by words without meaning, and which render their inventors no wifer than the moft heedlefs and unattentive!

Without *inftrumental*, or fecond caufes, there can be no regular courfe of nature; and without a regular courfe, nature could never be underftood. The order and courfe of things, and the experiments we daily make, fhew that there is a *mind*, that governs and actuates this mundane fyftem, as the proper real agent and caufe; the inferior and inftrumental caufe feems to be fire; with refpect to *attraction*, it cannot produce, and in that fenfe account for the phenomena, being itfelf one of the phenomena produced and to be accounted for. What is faid of forces refiding in bodies, whether attracting or repelling, it can only be confidered as a mathematical hypothefis, not as any thing real and exifting in nature.

The mechanical agency of the elements accords with the defcriptions and allufions of the facred fcriptures. The heathens were in fome degree acquainted therewith. When this doctrine was in their hands, a principle of intelligence was afcribed to the active elements, and they were taken for the Gods who govern the world. But with thofe who are taught that the TRUE GOD is diftinct from, and above the world of matter, though virtually prefent by a providential infpection and fuperintendance, it ferves only to enlarge and exalt their ideas by fetting before them the vifible evidence of *divine wifdom*, which with fo exquifite a contrivance, and fuch fimplicity of defign, hath adapted

adapted *physical causes* to the production of their respective effects.

We have now to consider, 4thly, the *mathematical principles of philosophy*. The celestial motions have been thought to resemble those exhibited to us in the phenomena of magnetism and electricity; these and the celestial bodies *seem* to act upon each other at a distance, without any observed intervening impulse. Accordingly many philosophers, both ancient and modern, have imagined that the planets are influenced by causes similar to those of these more familiar phenomena. But these philosophers had formed no accurate notions of the agency of the causes of the motions from which they attempted to derive an explanation; neither had they examined attentively the circumstances of the motions which they attempted to explain. At last, SIR ISAAC NEWTON contented himself with an investigation of *the laws observed in the agency* of the causes of the celestial motions, discovered that these laws were the same with those observed in the agency of the causes of the motion of common heavy bodies, and from this discovery gave a theory of *mathematical astronomy*. We are indebted, however, to KEPLER, for the generalization of the facts, which form the basis of the mathematical theory.

KEPLER'S LAWS.

Kepler's first law is, *that the planets, in revolving round the sun, describe equal areas in equal times.*

Kepler's second law is, *that the orbits described by the planets are ellipses, having the sun, or the primary planets, in the focus.*

Kepler's third law is, *that the squares of the*

periodical times of the planets are as the cubes of their mean distances from the sun. That is, as the square of the time which a planet A takes to revolve in it's orbit, is to the time which any other planet B takes to run through it's orbit; so is the cube of the mean distance of A from the sun, to the cube of the mean distance of B from the sun.

OF DEFLECTING FORCES.*

In consequence of the inertia of matter, all motion is considered as equable and rectilineal, and as being in a strait line with the direction of the moving force; and as preserving this direction until it be hindered or put out of it's way by some extrinsic cause.

If therefore a body moves in a *curve*, that *curvature* must proceed from some external force continually acting upon the body; and whenever that force ceases to act, the body will move forward in a right line, touching the curve in that point where the body is at the instant of time when the force ceases to act.

When you observe a change in the direction of any motion, you may *infer* the action of a force, whose direction crosses that of the former motion. This may be called a *deflecting force.*

The change of direction is measured by the angle contained between the former and the new direction.

When the motion of a body is *curvilineal, the deflection is continual,* and you may infer the continual action of a deflecting force. On the other hand, the continual action of a deflecting force produces a curvilineal motion.

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* Professor Robison's Outlines of Mechanical Philosophy, page 34 to 107.

In a curvilineal motion the change of direction is meaſured by the angle contained between the tangents to the curve.

A *curvilineal* motion is therefore always a *compound* motion; but the great bodies of this ſyſtem, as the planets, move round the ſun in curve lines; on theſe principles there muſt therefore be neceſſarily two powers acting on them, one impelling them to move in a ſtrait line, the other deflecting or bending them continually towards a center.

You may therefore conſider *deflecting* forces as always directed *to* or *from* a point; in the firſt caſe they are called *centripetal* forces, in the ſecond caſe they are called *centrifugal* forces. In general, they are termed CENTRAL forces; and the point, through which their direction always paſſes, is called the center of the forces.

Among the various curvilinear motions which may ariſe from the action of central forces, there is a circumſtance in which they all agree, and which enables the mathematician to inveſtigate the forces by which they are produced.

If a body moves in a curve line, A B C D E F, *fig.* 3, *pl.* 15, by means of a force always directed to a fixed point S, the curve is all in one plane, and the areas (A S B, A S C, A S D) deſcribed by the ſtrait line joining the body with the point S, are proportional to the times of deſcription; *i. e.* equal areas are deſcribed in equal times, unequal areas in unequal times. Thus the *triangular areas* A S B, B S C, C S D, &c. deſcribed by the ſtrait line joining the body with the point S, are proportional to the times of deſcription.

Let the time be divided into equal parts, let the body be acted on by an impulſe that will carry it from A to B, the firſt given particle of time; then in the ſecond particle it would go an equal

ſpace, and deſcribe the line B c equal to the line A B.

But when the body is arrived at B, let a deflecting (centripetal) force ſo act upon it, that while it's firſt impulſe would carry it to c, the deflecting force would carry it to V; complete the parallelogram, B V c c, and it is evident, from the doctrine of compound forces, that the body would in the ſecond particle of time deſcribe the diagonal B C.

Now as C c is parallel to S V, the triangles S B C, S B, are between the ſame parallel lines, and as ſuch, are (by geometry proved to be) equal; for the ſame reaſon the triangles S C D, S E F, are proved to be equal to S B A.

If any number of theſe triangles be added together, the total ſums, as A D S, F C S, will be proportional to the times wherein they are deſcribed.

If the lines A B, B C, be continued round a center, they will form a *polygon*, and if the ſides of the polygon be indefinitely increaſed in number, and indefinitely decreaſed in length, they will form a curve, a *circle*, or an *ellipſis*: and the propoſition will be true of theſe curves, that a line drawn from the center to a body in the circumference of the circle, or from the focus to a body in the circumference of the ellipſis, will *ſweep equal areas in equal times*.

The power, therefore, directed towards the given point S has no effect on the magnitude of the area deſcribed by the line ſuppoſed to be drawn from the body to that point. It may accelerate or retard the motion of the body, but affects not the area or ſpace deſcribed by the line. The line will ſtill continue to deſcribe the ſame ſpaces in equal times, about the given point, as it would have done, if no new force had acted on the body, but it had been permitted to proceed uniformly in the line of projection.

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As one impulſe towards the given point has no effect on the area or ſpace deſcribed by the ray or line from the body to that point, ſo any number of ſucceſſive impulſes directed to the ſame point can have no effect on the area; and if you ſuppoſe the power directed to that point, to act continually, it will bend the way of the body in motion into a curve, and may accelerate or retard it's velocity, but can never affect the area deſcribed in a given time by a line ſuppoſed to be drawn from the body to the given point, which will always be of an invariable quantity, equal to that which would have been deſcribed in the ſame time, if the body had proceeded uniformly in a right line from the beginning of the motion.

The converſe of the foregoing propoſition ſhews, that if a body A deſcribes a curve all in one plane, and if there be a point S ſo ſituated in this plane, that a line drawn therefrom to the circumference deſcribes proportional areas in proportional times, then is the body urged round by a force tending towards that center. In other words, the equable increaſe of the areas deſcribed by a line drawn from a body to a given point, is an indication that the direction of the power that acts upon the body, and that deflects it into a curve, is directed to that point.

By the ſame propoſition we may illuſtrate and explain the revolutions of the primary planets in elliptical orbits (not much differing from circles) round the ſun, who is in one of the foci of each ellipſis.

Let the ellipſis A B C D E F G H I K L M, *fig.* 4, *pl.* 15, repreſent the orbit of a planet moving therein round the ſun S, according to the order of the letters, the ſun S being in one of the foci of the ellipſis; let the time of it's revolution be divided into any number of equal parts,

S 3 ſuppoſe

ſuppoſe 12, in moving from A through B C D, &c. the planet approaches nearer the ſun, and the central tendency continually increaſing it's velocity, it goes through *greater arcs in equal times*, till it comes to G; from thence it's motion continually carries it to a greater diſtance from the ſun, and it deſcribes in equal times ſmaller and ſmaller arcs, till it returns to A, from whence it proceeds as before.

Now the triangular ſpaces paſſed over by a line drawn from the planet to the center of the ſun will be equal, becauſe in the planet's going the firſt half of the ellipſis from A to C, the arcs which may be conſidered as the baſe of the mixed triangles deſcribed in equal times, grow longer and longer, as the legs grow ſhorter, ſo as to preſerve the equability of the triangular ſpace: in the other half of the ellipſis in the planet's going from C to A, the arcs grow ſhorter; but this is compenſated by the greater length of the legs.

The ſum of what has been proved is, 1. that the areas or ſpaces revolving round an immoveable center are proportional to the times; and, 2d, that if a body revolving round a center deſcribes about it areas proportional to the times, the body is actuated by a force directed to that center.

But by Kepler's firſt law, we know "that the primary planets deſcribe round the ſun, and the ſecondary planets deſcribe round their reſpective primary planets, areas proportional to the times." From hence it is inferred, that the primary planets are retained in their orbits by forces which are always directed to the ſun; and that the ſecondary planets are retained in their orbits round their primary planets by forces which are always directed to thoſe primary planets.

Kepler's ſecond law is, "That the orbits deſcrib-
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ed round the ſun, and round the primary planets, are ellipſes, having the ſun, or the primary planet, in the focus." From hence it is inferred, that the accelerating force, by which a planet is retained in the different parts of it's elliptical orbit, is inverſely proportional to the ſquare of it's diſtance from the ſun, or from it's primary.

Kepler's third law is, "That the ſquare of the periodic times of planets revolving round common centers, are proportional to the cubes of their mean diſtances." From this it is inferred, that the forces, by which the planets are retained in their *different* orbits, are inverſely proportional to the ſquares of their diſtances from the ſun. The ſame reaſoning applies to the ſatellites.

Hence it is alſo inferred, that the forces, by which different planets are retained in their different orbits, are not forces of different kinds, but the ſame force operating at different diſtances.

The ſecondary planets accompany the primary planets by the action of a force always directed to the ſun, and inverſely proportional to the ſquare of the diſtance from the ſun.

*That the moon is a heavy body, and gravitates towards the earth in the ſame manner as terreſtrial bodies.**

Sir Iſaac Newton, conſidering that the power of gravity acts equally on all matter that is on or near the ſurface of the earth, that it is not ſenſibly leſs on the tops of the higheſt mountains, that it affects the air and reaches upward to the utmoſt limits of the atmoſphere, was induced to think it might be a more general principle, and extend to the heavens, ſo as to affect the moon at leaſt, which is the neareſt to us of all the bodies in the ſyſtem. He afterwards extended this principle ſtill further,

* Maclaurin's Sir Iſaac Newton's Diſcoveries, p. 214 to 265.

further, and ſhewed, that the planets conſiſted of the ſame gravitating ſubſtance of which the earth is formed.

The effects of the power of gravity upon terreſtrial bodies may be reduced to three claſſes. 1. When in conſequence thereof, a body at reſt, ſupported by ground, ſuſpended by a ſtring, or any otherways kept from falling, endeavours always to move. In ſuch caſes the effect of gravity is meaſured by the preſſure of the quieſcent body upon the obſtacle that hinders it's motion.

2. When a body deſcends in a vertical line, it's motion is then continually accelerated, in conſequence of the inceſſant action of the power of gravity; or if it be projected upwards in the ſame right line, it's motion is continually retarded by the ſame power acting inceſſantly upon it in a contrary direction. In ſuch caſes the power of gravity is meaſured by the acceleration or retardation of the motion produced in a given time by the power continued uniformly for that time.*

3. When a body is projected in any direction different from the vertical line, the direction of it's motion is continually varied, and a curve line is deſcribed in conſequence of the inceſſant action of gravity; which in ſuch caſes is meaſured by the flexure or curvature of the line deſcribed by it; for the power muſt be greateſt that deflects the courſe of the body moſt from the tangent or direction in which it was projected.

Effects of each kind of the power of gravity continually fall under your obſervations near the ſurface of the earth; for the ſame power which renders bodies heavy while they are at reſt, accelerates their motion when they deſcend perpendicularly, and bends their motion into a curve line when

* See Lecture on Mechanics.

when they are projected in any other direction than that of their gravity.

We can judge only of the powers that act on the celestial bodies by the effects of the last kind; we see bodies near the earth falling towards it; but this is a proof of the moon's gravity, which cannot be obtained unless the present state of things were dissolved.

When a body is projected in the air, you do not see it fall in the perpendicular towards the earth, but you see it falling every moment *from the tangent to the curve*, that is, from the direction in which it would have moved, if it's gravity had not acted for that moment.

And this proof is obtained of the moon's gravity; for though you do not see her falling directly towards the earth in a right line, yet you observe her every moment descending towards the earth from the right line, which was the direction of her motion at the beginning of that moment, and this is as evident a proof of her being acted upon by gravity or some power similar to it, as her rectilineal descent would be, if she were allowed to fall freely to the earth.

If we were in possession of engines of a sufficient force, bodies might be projected from them so as not only to be carried a vast way without falling to the earth, but so as to move over a quarter of a great circle thereof, or (abstracting from the resistance of the air) to move round the earth without touching it, and after returning to their first place, commence a new revolution with the same force which they first received from the engine, and after that a third, and thus revolve as a moon or satellite round the earth for ever.

If this could be effected near the earth's surface, it might be done higher in the air, or even as high as the moon, could the engine or an equivalent

valent power be carried up and made to act there. By increasing the force of the power, a body proportionally larger might be thus projected, and by a power sufficiently great, a body not inferior to the moon, might be at first put in motion, and being perpetually restrained by it's gravity from going off in a strait line might for ever revolve about the earth.

Thus *Sir Isaac Newton* saw, that the curvilineal motion of the moon in her orbit, and of any projectile at the surface of the earth, were phenomena of the same kind, and might be explained upon the same principle extended from the earth, so as to reach the moon; and that the moon was only a larger projectile that received it's motion in the beginning of things from the Almighty Author of the universe.

But to make this more evident, it was necessary to shew, that the powers which act on the moon, and on projectiles near the earth, and which bend their motions in a curve line, were directed to *the same center*, and agreed in the *quantity of their force*, as well as in their direction.

All we know of force, relates either to it's direction or quantity, and a constant coincidence or agreement in these two respects is sufficient ground to conclude them to be the same, or similar phenomena, derived from the same or like causes.

Now I shewed you in the Lecture on mechanics, that the gravity of heavy bodies is directed towards the center of the earth; and it appears from Kepler's 1st law, as I have shewn you in this Lecture, that the power which acts on the moon, incessantly bending her motion into a curve, is directed towards the same center; for astronomers find, that the moon does not describe an exact circle about the earth, but an ellipse, and that she

ſhe approaches to the earth, and then recedes from it in every revolution, but ſtill ſo as to have her motion accelerated while ſhe approaches to the center of the earth, and retarded as ſhe recedes from it, deſcribing equal areas in equal times; an indication, as you have already ſeen, that ſhe is acted on by a power directed accurately or nearly towards the center.

There is, therefore, a power which deflects the moon from a rectilineal courſe, and which like gravity makes her deſcend towards the center of the earth; ſo that if the projectile force were deſtroyed, ſhe would fall to the earth in a direct line; and as this power acts inceſſantly, bending every moment her path into a curve, it would make her deſcend to the earth with an accelerated motion, like that of heavy bodies in their fall.

It remains, therefore, only to ſhew, that the power which acts on the moon, agrees with gravity in the quantity of it's force, as well as in other reſpects. But before we compare them in this particular, I muſt obſerve to you, that the power which acts upon the moon, is not the ſame at all diſtances, but is always greateſt when ſhe is neareſt the earth.

To be ſatisfied of this, it is only neceſſary to obſerve, as before, that to bend the motion of a body into a curve when it moves with a greater velocity, requires more power than when it deſcribes the ſame curve with a leſs velocity.

Though what I have juſt aſſerted is ſufficiently obvious, it may appear more fully by conſidering a diagram; imagine, therefore, a tangent, *fig.* 5, *pl.* 15, drawn at the beginning of a ſmall arc deſcribed by the body; and as this is the line which the body would have followed, if no new power had acted upon it, the effect of that power is eſtimated by the depreſſion of the other extremity of the

the arc under that tangent: now it is plain, that in arcs of the ſame curvature, the greater the arc is, the farther muſt one extremity of it fall below the tangent drawn at the other extremity; and conſequently, when a body deſcribes a greater arc, it muſt be acted on by a greater power than when it deſcribes a leſs arc in the ſame time. Now as the moon approaches the earth, her motion is accelerated, is ſwifteſt at her leaſt diſtance, ſloweſt at her greateſt diſtance, and the forces ſhe deſcribes at her greateſt and leaſt diſtance have the ſame curvature, therefore the force which acts upon her at her leaſt diſtance when her motion is ſwifteſt, muſt be the greateſt force.

It will not now be difficult to ſee according to what law this power varies at her leaſt and greateſt diſtance from the earth. To render this eaſier, let us aſſume a ſimple caſe, and ſuppoſe that her leaſt diſtance is half that of her greateſt. If this were true, the moon would move with double velocity in her leaſt diſtance; and the ſpace deſcribed by a ray from her to the earth might be equal to the ſpace deſcribed in the ſame time at her greateſt diſtance; ſo that ſhe would deſcribe at her leaſt diſtance an arc in one minute equal to the arc ſhe would deſcribe in two minutes at her greateſt diſtance, and would fall as much below the tangent at the beginning of the arc in one minute in the lower part of her orbit, or the perigæum, as in two minutes in the higher part of her orbit or her apogæum.

If therefore her projectile force was deſtroyed at her leaſt diſtance, ſhe would fall towards the earth as much in one minute, as in two minutes if her projectile force was deſtroyed at her greateſt diſtance.

But the ſpaces deſcribed by a falling body are as the ſquares of the times, and ſuch a body deſcends through

through a quadruple ſpace in a double time; ſo that the moon deſcending freely would neceſſarily fall four times as far in two minutes as in one minute; that is, through four times as much ſpace in one minute at her leaſt diſtance, as at her greateſt diſtance in the ſame time.

But the forces with which heavy bodies deſcend are in the ſame proportion as the ſpaces deſcribed, in conſequence of thoſe forces, in equal ſmall parts of time; conſequently the force which acts at the leaſt diſtance is quadruple that which acts at a greater diſtance, when the latter is ſuppoſed to be double the former; or the forces are as 4 to 1, when the diſtances are as 1 to 2. The force therefore which acts upon the moon, and bends her into a curvilinear orbit, increaſes as the diſtance from the center of the earth decreaſes, ſo as to be quadruple at half that diſtance.

In the ſame manner it is ſhewn, that if her leaſt diſtance was the third part only of her greateſt diſtance, her velocity would be triple at the leaſt diſtance, to preſerve the equability of the areas deſcribed by a ray drawn from her to the center of the earth; and that ſhe would be acted upon there by a power, which would have the ſame effect in one minute, as in three minutes at her greateſt diſtance; ſo that if ſhe was allowed to deſcend freely from each diſtance, ſhe would fall 9 times as far from the leaſt diſtance as from the greateſt in the ſame time; conſequently the power itſelf which cauſes her to deſcend would be nine times greater at the third part of the diſtance, or the diſtances being as 1 to 3, the force would be as 9 to 1, or inverſely as the ſquares of the diſtances.

In the ſame manner it appears, that when the greateſt and leaſt diſtances are ſuppoſed to be in any proportion of a greater to a leſs number, the velocities of the revolving planet are in the inverſe ratio

ratio of the ſame numbers; and that the powers which deflect or bend it's motion into a curve, are in the inverſe ratio of thoſe numbers.

To conſider this in general, let T, *fig.* 5, *pl.* 15, repreſent the center of the earth, A L P the moon's elliptical orbit, A the apogæum, P the perigæum, A H and P K the tangents at thoſe points, A M and P N any ſmall arcs deſcribed by the moon in equal times at thoſe diſtances, M H, N K, the ſubtenſes of the angles of contact, terminated by the tangents in H and K; then M H and N K will be equal to the ſpaces that would be deſcribed by the moon, if allowed to fall freely from the reſpective places A and P in equal times; and will be in the ſame proportion to each other, as the powers which act upon the moon, and inflect her courſe at thoſe places.

Let A m be taken equal to P N, and m h parallel to A P meet the tangent at A in h; now as the curvature of the ellipſe is the ſame at A as at P, m h is equal to K N; and if the moon was to fall freely from the places P and A towards the earth, her gravity would have a greater effect at P than at A, in equal times, in proportion as m h is greater than M H. But m h is the ſpace which the moon would deſcribe freely by her gravity at A, in the time which m h would be deſcribed by her projectile motion at A, and M H is the ſpace through which ſhe would deſcend freely by her gravity at A in the time in which A H would be deſcribed by her projectile motion; and theſe ſpaces being as the ſquares of the times, it follows, that m h is to M H, as the ſquare of A h to the ſquare of A H, or (becauſe of the equality of the areas T A H, T P K) as the ſquare of T P to the ſquare of T A.

Therefore the gravity at P is to the gravity at A, as the ſquare of T A to the ſquare of T P; that is,

is, the gravity of the moon towards the earth increafes in the fame proportion, as the fquare of the diftance from the center of the earth decreafes.

Sir Ifaac Newton fhews the univerfality of this law, in all her diftances, from the direction of the power that acts upon her, and from the nature of the *ellipfis*, the line which fhe defcribes in her revolution; and it follows from the *properties* of this curve, that if you take fmall arcs defcribed by the moon in equal times, the fpace by which the extremity of any arc defcends towards the earth below it's tangent at the other extremity, is always greater in proportion as the fquare of the diftance from the focus is lefs; from which it follows, that the power which is proportional to this fpace obferves the fame proportion.

The moon's orbit, according to aftronomers, differs not much from a circle of a radius equal to 60 times the femi-diameter of the earth; and the circumference of her orbit is therefore about 60 times the circumference of a great circle of the earth.

From this the circumference of the moon's orbit is eafily computed, and as fhe finifhes her revolution in 27 days, 7 hours, and 43 minutes, it is alfo eafy to calculate what arc fhe defcribes in one minute.

The next thing is to compute how much this arc of one minute is deflected below a tangent drawn at the other end: now geometricians prove, that this fpace is nearly a third proportional to the diameter of her orbit, and the arc fhe defcribes in a minute; whence by an eafy calculation this fpace is found to be about 16 feet 1 inch.

But you have feen that this fpace was defcribed in confequence of her gravity, or tendency towards the earth, which is therefore a power, that at the diftance of 60 femi-diameters of the earth,

is

is able to make her defcend in one minute through 16 feet 1 inch.

Now, as this power increafes as fhe approaches the earth, let us fee what it's force would be at the furface thereof; and for this purpofe, let us fuppofe her to defcend fo low in her orbit as at her leaft diftance to pafs by the furface of the earth; fhe would then be 60 times nearer to the center of the earth, and move with a velocity 60 times greater, that the areas defcribed by a line drawn from her to that center in equal times, might ftill continue equal.

The moon therefore, paffing by the earth at her loweft ebb, would defcribe an arc in one fecond of time, (the 60th part of a minute) equal to that fhe defcribes in one minute at her prefent mean diftance, and would fall as much below the tangent at the beginning of the arc in a fecond, as fhe falls from the tangent at her mean diftance in a minute; that is, fhe would fall near the furface of the earth 16 feet 1 inch in one fecond of time.

Now this is exactly the fame fpace, through which all heavy bodies are found by experience to defcend by their gravity near the furface of the earth. The moon, therefore, would defcend at the furface of the earth with the fame velocity, and every way in the fame manner, as heavy bodies fall towards the earth; and the power which acts upon the moon, agreeing in *direction* and *force* with the gravity of heavy bodies, and acting inceffantly every moment, as their gravity does, they muft be of the fame kind, and proceed from the fame caufe.

Thus *Sir Ifaac Newton* fhewed, that the power of gravity is extended to the moon; that fhe is heavy, as all bodies belonging to the earth are found to be; and that fhe is retained in her orbit by

by the ſame cauſe which occaſions a ſtone, a bullet, or any other projectile, to deſcribe a curve in the air. If the moon or any part of her were brought down to the earth, and projected in the ſame line, and with the ſame velocity as a terreſtrial body, it would move in the ſame curve. On the other hand, if any body was carried from our earth to the diſtance of the moon, and was projected in the ſame direction and with the ſame velocity with which the moon is moved, it would proceed in the ſame orbit which the moon deſcribes, and with the ſame velocity. Thus the moon is a projectile, and the motion of every projectile gives an image of the motion of a ſatellite or moon.

That the primary planets are heavy bodies, and gravitate towards the ſun; and that the ſecondary planets gravitate towards their reſpective primaries.

Obſervation proves, that each of the primary planets bend their path about the center of the ſun; are accelerated as they approach to him, and are retarded as they recede from him; always deſcribing equal areas in equal times; from whence it follows, that the power by which they are deflected muſt be directed to the ſun. This power alſo varies always in the ſame manner as the gravity of the moon towards the earth.

The ſame reaſoning, by which the gravity of the moon towards the earth at her greateſt and leaſt diſtances were compared together, may be applied in comparing the powers which act on any primary planet at it's greateſt and leaſt diſtances from the ſun; and it will appear, that theſe powers increaſe as the ſquare of the diſtances from the ſun decreaſe.

But the univerſality of this law, and the uniformity of nature, ſtill further appear, by comparing the motions of the different planets.

The power which acts on a planet that is nearer the ſun, is manifeſtly greater than that which acts on a planet more remote, both becauſe it moves with more velocity, and becauſe it moves in a leſs orbit, (which has more curvature, and of courſe the body requires more force to be more deflected from it's rectilinear courſe.) By comparing the motions of the planets, it is found, that the velocity of a nearer planet is greater than that of one more remote, in proportion as the ſquare root of the number expreſſing the greater diſtance, to the ſquare root of the number expreſſing the leſſer diſtance; ſo that if one planet be 4 times farther from the ſun than another planet, the velocity of the firſt would be half the velocity of the latter, and the nearer planet would deſcribe an arc in 1 minute equal to the arc deſcribed by the higher planet in 2 minutes; and the nearer planet would deſcribe, by it's gravity, four times as much ſpace as the other would deſcribe in the ſame time; by the law of falling bodies, the gravity of the nearer planet would therefore appear to be quadruple, from the conſideration of it's greater velocity only. But further, as the radius of the leſſer orbit is ſuppoſed to be 4 times leſs than the radius of the other, the leſſer orbit muſt be 4 times more curve, and the extremity of a ſmall arc of the ſame length will be four times farther below the tangent drawn at the other extremity in the leſſer orbit than in the greater; ſo that though the velocities were equal, the gravity of the nearer planet would on this account only be found to be quadruple.

On both theſe accounts together, the greater velocity of the nearer planet, and the greater curvature

vature of it's orbit, the deflecting force, or it's gravity towards the fun, muft be fuppofed 16 times greater, though it's diftance from the fun is only 4 times lefs than the other; that is, when the diftances are as 1 to 4, the gravity is reciprocally as the fquares of thefe numbers, or as 16 to 1. By comparing the motions of all the planets it is found, that their gravities decreafe as the fquares of their diftances from the fun increafe.

The fame principle that governs the motion of the planets in the great folar fyftem, governs alfo the motion of the fatellites in the leffer fyftem, of which the greater is compofed.

There is the fame harmony in their motions compared with their diftances, as in the great fyftem. Jupiter's fatellites are continually bent from the lines that are the direction of their motions, each defcribing equal areas in equal times, by a ray drawn to the center, to which their gravity is therefore directed.

The nearer fatellites move with greater celerity, in the fame proportion as the nearer primary planets move more fwiftly round the fun; and their gravity therefore varies according to the fame law. The fame is to be faid of Saturn's fatellites.

There is, therefore, a power that preferves the fubftance of thefe planets in their various motions, acts at their furfaces, and is extended around them, decreafing in the fame manner as that which is extended from the earth and fun to all diftances.

They accompany their primary planets in their motion round the fun, and move about them at the fame time, with the fame regularity as if their primaries were at reft. It is as in a fhip, or in any fpace carried uniformly forward, in which the natural actions of bodies are the fame as if the fpace was at reft, being no way affected by that motion which is common to all the bodies.

As every projectile, while it moves in the air, gravitates towards the ſun, and is carried along with the earth about the ſun, while it's own motion in it's curve is as regular as if the earth were at reſt; ſo the moon, which is only a greater projectile, muſt gravitate towards the ſun, and while it is carried along with the earth about the ſun, is not hindered by that motion from performing it's monthly revolutions towards the earth. It is the ſame with reſpect to the other ſecondary planets.

Thus the motions in the great ſolar ſyſtem, and in the leſſer particular ſyſtems of each planet, are conſiſtent with each other, and are carried on in a regular harmony, without any confuſion or mutually interfering with one another, except what neceſſarily ariſes from ſmall inequalities in the gravities of the primary and ſecondary planets, and the want of exact parallelîſm in the direction of theſe gravities.

Obſervation ſhews, that the deflection of the moon to the earth, and of the planets to the ſun, is accompanied by an equal and oppoſite deflection of the earth to the moon, and of the ſun to the planets; from which it is inferred, that the forces which produce theſe deflections are *mutual*, *equal*, and *oppoſite*.

As the planets are deflected towards each other, and as theſe deflections are inverſely proportional to the ſquare of the diſtance from the planet towards which they are inflected; it follows, that all the bodies of the ſolar ſyſtem turn towards each other with forces which are inverſely proportional to the ſquare of the diſtances.

The curve which a body deſcribes determines the law of it's gravitation, or the relation which ſubſiſts between the intenſity of the gravitating force, and the diſtance from the point to which it gravitates.

If

If the gravitation of every particle of gravitating matter is ſuppoſed to be the ſame in the ſame circumſtances, then the relation which is obſerved between the diſtances and the periodic times, will determine the proportion of *gravitating* matter in a planet; and on this ſuppoſition it has been concluded from the phenomena, that this proportion is the ſame in all. But as this ſuppoſition is not formed from any direct arguments, all that can be juſtly inferred from this obſerved relation is, that the gravitation of each planet, taken *in cumulo*, is proportional to it's quantity of gravitating matter.

Of the Center of the Solar System.

Sir Iſaac Newton having found that the celeſtial bodies gravitate towards each other, and towards all other bodies in the ſyſtem, neither of them, nor indeed any body in the whole ſyſtem, can be ſuppoſed to be void of all motion.

The center of gravity of the whole ſyſtem is the only point therein, which can be ſuppoſed quieſcent; it is the only immoveable point, round which all the bodies in the ſyſtem move with various motions.

On an accurate examination of the tendencies of the planets, it is found, that the center round which each planet revolves, is not the center of the ſun, but the point which is the common center of gravity of the ſun and planet, whoſe revolution is conſidered. Thus the maſs of the ſun being to that of Jupiter, as 1 to $\frac{1}{1067}$ and the diſtance of Jupiter from the ſun being to the ſun's ſemidiameter in a ratio ſomewhat greater, it follows, that the common center of gravity of Jupiter and the ſun is not far diſtant from the ſurface of the ſun.

By the ſame methods of reaſoning, it is found, that the common center of gravity of Saturn and the ſun falls within the ſurface of the ſun; and alſo, that if all the planets were placed on the ſame ſide of the ſun, the common center of gravity of the ſun and all the planets, would ſcarce be one of his diameters diſtant from his center.

It is about this center of gravity, that the planets revolve; and the ſun himſelf oſcillates round this center in proportion to the actions of the planets exerted on him.

When, therefore, the motion of two bodies, whereof the one revolves round the other, is conſidered rigorouſly, the central body ſhould not be regarded as fixed, as they both revolve round their common center of gravity; but the ſpaces they deſcribe round this common center being in the inverſe ratio of their maſſes, the curve deſcribed by the body which is the greateſt maſs, is almoſt inſenſible; for which reaſon, the curve deſcribed by the body, whoſe revolution is ſenſible, is only to be conſidered, and the ſmall motion of the central body, which is regarded as fixed, is neglected.

The earth and the moon therefore revolve round their common center of gravity, and this center of gravity revolves round the center of gravity of the earth and ſun. The caſe is the ſame with Jupiter and his moons, Saturn and his ſatellites, and with the ſun and all the planets. And the ſun, according to the different poſition of the planets, moves ſucceſſively on every ſide around the common center of gravity of our planetary ſyſtem.

This center is the point where all the bodies of our planetary ſyſtem would meet, if their projectile forces were deſtroyed, though the ſun is in perpetual agitation, being, as I have ſhewn you, ſo

near

near it, he may with propriety be confidered by aftronomers as the center of the folar fyftem.

Gravity produces fome fmall irregularities in the motion of the planets.

The regularity of the planetary motions is difturbed by their mutual gravitation, each difturbing the motions of the other, with a force proportional to it's quantity of matter directly, and to the fquare of it's diftance from them inverfely. In order to calculate thefe difturbances, it was neceffary for mathematicians previoufly to afcertain the quantity of matter in the fun and planets.

When a fleet of fhips is carried away by a current that affects them equally, it has no effect on their particular motions amongft themfelves, nor is the motion from the current difcovered by them, unlefs they have fome body in fight, that is not affected thereby in the fame manner. The regularity in the motions of a planet A round the fun, would not be difturbed by the gravitation to a planet B, if the fun and the planet A did gravitate to B with equal forces, and in parallel directions; and the difturbance of the motion of A, arifes from the inequality and obliquity of the gravitations of the fun, and of A and of B.

In confequence of this difturbing force, the motion of the earth in it's orbit is retarded, from the time that Jupiter is in oppofition to the time that he is in quadrature with the fun. It is then accelerated till he is in conjunction, then retarded till he is in quadrature, and then accelerated till he is again in oppofition.

The earth's gravitation to the fun is increafed while Jupiter is in or near the quadratures, and diminifhed while he is in or near the conjunction and oppofition.

The augmentation of the earth's gravitation to the ſun is greateſt when Jupiter is in quadrature, being then about $\frac{1}{25000}$ of the whole gravitation to the ſun. The diminution of the earth's gravitation to the ſun is greateſt when Jupiter is in oppoſition, being then about $\frac{1}{1000}$ of the whole gravitation.

The diminution of the earth's gravitation to the ſun when Jupiter is in conjunction, is about $\frac{1}{17600}$ of the whole gravitation.

In conſequence of this change in the earth's gravitation to the ſun, the line of the apſides of the earth's orbit changes it's place in the heavens, ſometimes advancing, and ſometimes retreating; but, on the whole, advancing, becauſe the earth's gravitation to the ſun is more diminiſhed than it is augmented.

In like manner, the aphelion of any inferior planet advances in conſequence of the gravitation to the ſuperior planets; but the aphelion of a ſuperior planet retreats in conſequence of it's gravitation to the inferior planets. For theſe reaſons, and becauſe Jupiter and Saturn are much larger than the inferior planets, the aphelia of all the planets, excepting Saturn, advance, while the aphelion of Saturn retreats.

The accelerations and retardations of the planets Mercury, Venus, the Earth, and Mars, ariſing from their mutual gravitations, and their gravitations to Jupiter, nearly compenſate each other; and no effects of them are perceived in any long tract of years. But the poſition of the aphelia of Jupiter and Saturn is ſuch, that the retardations of Saturn ſenſibly exceed the accelerations; ſo that the anomaliſtic period of Saturn is increaſing, at preſent, about a day in a century. On the contrary, the period of Jupiter is diminiſhing.

The diſturbances occaſioned by the mutual gravitations of the planets and comets are conſider-

able,

able. The comet of 1777 has ſuffered a remarkable change in it's motions by the action of Jupiter.

The earth's motion round the ſun is remarkably affected by the moon.

In conſequence of the mutual gravitations of the planets, the nodes of a diſturbed planet retreat on the orbit of the diſturbing planet. Hence the nodes of all the planets retreat on the ecliptic, except that of Jupiter, which advances by retreating on the orbit of Saturn, from which it ſuffers the greateſt diſturbance.

OF THE APPROACH AND RECESS OF THE PLANETS TO AND FROM THE SUN IN EVERY REVOLUTION.

Having ſhewn you that the forces which produce the regular motions of the planets, vaſtly exceed thoſe that diſturb them, I ſhall explain more fully, how the motions in their orbits proceed from the actions of thoſe powers; and how the planet is made to aſcend and deſcend by turns, while it revolves about the center of it's gravitation.

We have nothing ſimilar to this in the motion of heavy bodies at the earth's ſurface; but you muſt remember, that the force, with which heavy bodies are projected from our moſt powerful engines, is inconſiderable, compared with the motions which their gravity could generate in them in a few minutes; and they move over ſuch ſmall ſpaces when compared with their diſtances from the center of the earth, that their gravity is conſidered as acting in parallel lines, without any ſenſible error; ſo that the centrifugal force ariſing from the rotation about that center, is altogether neglected.

But when the motion of a projectile in the larger ſpaces is examined, and traced in it's orbit, it is neceſſary to take in the centrifugal force, ariſing from it's motion of rotation about that

center;

center; and then it will appear, that there are indeed ſome laws of gravity, which would make the body approach to the center continually, till it fall into it, but that there are other laws which *make* bodies to *approach*, and *ſuffer* them to *recede* from it by turns.

If a planet at B, *fig.* 6, *pl.* 15, gravitates, or is attracted toward the ſun, ſo as to fall from B to y in the time that the projectile force would have carried it from B to X, it will deſcribe the curve B Y by the combined action of theſe two forces, in the ſame time that the projectile force ſingly would have carried it from B to X, or the gravitating power ſingly have cauſed it to deſcend from B to y; and theſe two forces being duly proportioned, and perpendicular to each other, the planet obeying them both, will move in the circle B Y T.

But if whilſt the projectile force would carry the planet from B to b, the ſun's attraction (which conſtitutes the planet's gravitation) ſhould bring it down from B to 1, the gravitating power would then be too ſtrong for the projectile force, and would cauſe the planet to deſcribe the curve B C. When the planet comes to C, the gravitating power (which always increaſes as the ſquare of the diſtance from the ſun diminiſhes) will be yet ſtronger for the projectile force; and by conſpiring in ſome degree therewith, will accelerate the planet's motion all the way from C to K; cauſing it to deſcribe the arcs B C, C D, D E, E F, &c. all in equal times. Having it's motion thus accelerated, it thereby gains ſo much centrifugal force, or tendency to fly off, at K in the line K k, as overcomes the ſun's attraction; and the centrifugal force being too great to allow the planet to be brought nearer the ſun, or even to move round him in the circle K l m n, &c. it goes off, and aſcends in the curve K L M N, &c. it's motion decreaſing as

as gradually from K to B, as it increafed from B to K; becaufe the fun's attraction now acts againft the planet's projectile motion, juft as much as it acted with it before. When the planet has got round to B, it's projectile force is as much diminifhed from it's mean ftate about G or N, as it was augmented at K; and fo, the fun's attraction being more than fufficient to keep the planet from going off at B, it defcribes the fame orbit over again, by virtue of the fame forces or powers.

A double projectile force will always ballance a quadruple power of gravity. Let the planet at B have twice as great an impulfe from thence towards X, as it had before; that is, in the fame length of time it was projected from B to b, as in the laft example, let it now be projected from B to c; and it will require four times as much gravity to retain it in it's orbit; that is, it muft fall as far as from B to c: otherwife it could not defcribe B D, as is evident by the figure. But, in as much time as the planet moves from B to C in the higher parts of it's orbit, it moves from I to K, or from K to L, in the lower part thereof; becaufe, from the joint action of thefe two forces, it muft always defcribe equal areas in equal times, throughout it's annual courfe. Thefe areas are reprefented by the triangles B S C, C S D, D S E, E S F, &c. whofe contents are equal to one another, quite round the figure.

As the planets approach nearer the fun, and recede farther from him, in every revolution, there may be fome difficulty in conceiving the reafon why the power of gravity, when it once gets the better of the projectile force, does not bring the planets nearer and nearer the fun in every revolution, till they fall upon and unite with him; or why the projectile force, when it once gets the better of gravity, does not carry the planets farther and

farther

farther from the ſun, till it removes them quite out of the ſphere of his attraction, and cauſes them to go on in ſtrait lines for ever afterward: but by conſidering the effects of theſe powers, this difficulty will be removed. Suppoſe a planet at B to be carried by the projectile force as far as B to b, in the time that gravity would have brought it down from B to 1; by theſe two forces it will deſcribe the curve C; when the planet comes down to K, it will be but half as far from the ſun S, as it was at B; and therefore, by gravitating four times as ſtrongly towards him, it would fall from K to V in the ſame length of time that it would have fallen from B to 1 in the higher part of it's orbit, that is, through four times as much ſpace; but it's projectile force is then ſo much increaſed at K, as would carry it from K to k in the ſame time; being double of what it was at B, and is therefore too ſtrong for the gravitating power, either to draw the planet to the ſun, or cauſe it to go round him in the circle K l m n, &c. which would require it's falling from K to w, through a greater ſpace than gravity can draw it, whilſt the projectile force is ſuch as would carry it from K to k; and therefore, the planet aſcends in it's orbit K L M N, decreaſing in it's velocity for the cauſes already aſſigned.

THE MOON'S IRREGULARITIES.

There is nothing that ſhews better the excellency of the NEWTONIAN philoſophy, or more clearly demonſtrates the truth of it's principles, than it's ſo eaſily, and clearly, accounting for thoſe many *irregularities* of motion, to which all *ſecondary planets*, and the *moon* in particular, are ſubject.

Though theſe are called *irregularities*, yet they are not to be apprehended as *random* or *for-*

tuitous

tuitous ones, but ſuch as are *regular* under the like circumſtances, and ſubject to *numbers* and *calculation*.

For it was by obſerving the *period* of theſe lunar *inequalities*, that Dr. *Halley* was enabled to foretel an eclipſe of the ſun, with an exactneſs little inferior to the obſervation itſelf.

It hath been ſeen before, that *gravitation* is a principle belonging to all *gravitating matter*; and that bodies, deſcribing orbits about another placed in the center of their motion, by a *centripetal* and *projectile* force, deſcribe *equal areas in equal times*.

As this is the law by which the *primary planets* regulate their motions about the ſun, ſo likewiſe, was there *no ſun*, by the ſame law would the *moon* regulate her motion about the *earth*.

This tendency of the *moon* towards the *ſun*, then, is the cauſe of thoſe *inequalities* in her motion, which are ſtiled her

IRREGULARITIES.

Theſe are commonly reckoned eight, ariſing from cauſes now to be mentioned.

I. That *variation*, whereby, if we ſuppoſe E the earth, *fig.* 7, *pl.* 15, and the circle A B C D the orbit of the *moon*, while the *moon* deſcribes the quadrant A B, that is, while ſhe goes from the *quadrature* to the *conjunction*, the force tending towards the *ſun* at S, conſpires with the force tending towards the earth at E, and therefore *accelerates* her motion. But while ſhe goes from the *conjunction* B to the next *quadrature* C, the force tending towards the ſun will act contrary to the force tending towards the earth, and therefore will *retard* her motion.

In the ſame manner while ſhe goes from the *quadrature* C, to the next *ſyzygy* D, the ſame force, tending

tending towards S, will *accelerate* her again; but while ſhe goes from thence to the *quadrature* at A, it will *retard* her again.

The moon therefore, in her monthly revolution about the earth, is, by this action of the ſun, *alternately* accelerated and retarded.

II. This force tending towards the ſun being the DISTURBING FORCE, or that force which prevents the moon from deſcribing about the earth *equal areas* in *equal times*, will be greateſt at the OCTANTS.

For this force being reſolved into two others, after Sir *I. Newton*'s manner, *one* of them at the quadratures, or ſyzygies, will be found to point *from* or *towards* E the center of the earth directly, and therefore will not hinder the moon from deſcribing equal areas in equal times; the *other*, likewiſe, in thoſe places will be found to tend towards the center of the ſun, and therefore neither of them will prevent the moon there from deſcribing equal areas in equal times, *i. e.* will not at the quadratures diſturb the moon's motion at all.

But when the moon is in the *octants*, as at L, *fig.* 8, *pl.* 15, this force being reſolved into *two others*, one of them, as L H, will point *directly to*, or *from*, the center of the earth, and therefore will *increaſe* or *diminiſh* the moon's tendency towards the earth, but not hinder her from deſcribing equal areas in equal times. But the other, as L I, or H G, points neither towards the *center* of the earth, *nor* ſun, and therefore, in the *octants*, prevents her deſcribing equal areas in equal times.

But this being the mid-way between the *quadrature* and the *ſyzygy*, in both which places this diſturbing force doth not prevent the moon from deſcribing equal areas in equal times, it follows, that at the *octants*, this *diſturbing force* will be *greateſt of all*.

And

And for this reaſon it hath always been found more difficult to obtain the moon's place in the *octants* agreeing with obſervation, than at the *ſyzygies*, or *quadratures*.

III. The moon's orbit is more *curved* in the *quadratures* than in the *ſyzygies*.

For her motion being accelerated during her progreſs from the *quadratures* to the *ſyzygies*, in the *ſyzygies* her motion will be *quicker* than it ought otherwiſe to be, and therefore her *centripetal* force *leſs* than it would otherwiſe be. She will therefore at the *ſyzygies* deſcribe the portion of a *larger* curve, which conſequently will be *leſs curved* than a ſmaller. That is, inſtead of deſcribing the curve A B, *fig.* 9, *pl.* 15, or C D, ſhe will deſcribe the curve E F, or G K.

On the other hand, while the moon goes from the *ſyzygies* to the *quadratures*, her motion is continually retarded, and therefore, at the quadratures, her motion will be *ſlower* than it would otherwiſe be. At the *quadratures* therefore the moon will deſcribe the portion of a *leſſer* curve, which therefore will be *more curved* than a *larger* curve. That is, inſtead of deſcribing the curve A B, or C D, ſhe will deſcribe the curve E F, or G K, *fig.* 10, *pl.* 15.

Therefore, at the *quadratures*, the moon's orbit is *more curved* than at the *ſyzygies*.

IV. Since theſe *irregularities* in the moon's motion proceed, as was ſaid, from the action of the ſun, it will follow, that where the action of the ſun is *greateſt*, the *irregularities* ariſing from it will be *greateſt* alſo. But the *nearer* the earth is to the ſun, the *greater* will be the action of the ſun upon the *moon*. And the *more* ſhe tends towards the ſun, the *leſs* will ſhe tend towards the earth.

When therefore the earth is at the *perihelion* P, *fig.* 11, *pl.* 15, and conſequently at it's *leaſt* diſtance

tance from the *ſun*, the action of the ſun upon the moon will be *greateſt*, and deſtroy more of it's tendency towards the earth than at any other diſtance, as S D, S C, S B, &c.

Therefore when the earth is at the *perihelion* P, the moon will deſcribe a larger orbit about the earth, than when the earth is at any other diſtance from the ſun, and conſequently then, her *periodical* time will be the *longeſt*.

But the earth is at it's perihelion in the winter, and, conſequently, then the moon will deſcribe the *outermoſt* circle about the earth, and her periodical time will be the longeſt. And this agrees with obſervation.

For the ſame reaſon, when the earth is at it's *aphelion* A, the tendency of the moon towards the earth will be the *greateſt*, and conſequently her periodical time the *leaſt*. And in this caſe, which will be in the ſummer, ſhe will deſcribe the *innermoſt* circle about the earth.

V. Since the moon, from what has been ſaid, appears to deſcribe an *elliptical* orbit about the earth E, *fig.* 12, *pl.* 15, in the focus of it; and ſince her centripetal force towards the earth, by means of the action of the ſun, is continually *increaſing*, or *decreaſing*, but not equably, that is, ſometimes *leſs*, and ſometimes *more*, than in the *inverſe duplicate* proportion of the diſtance of the moon from the earth; therefore, in this caſe, the line of the moon's apſides A B will be continually going *backwards*, or *forwards*. That is, the axis A B will not always lie in that ſituation, but go *backwards* into the ſituation K L, or *forwards* into the ſituation F G.

Since however, taking one whole revolution of the *moon* about the earth, the action of the ſun *more diminiſhes* the tendency of the moon towards the earth, than it *augments* it, therefore the motion of

of the apſides *forwards*, *exceeds* their motion *backwards*. Upon the whole therefore the *apſides* of the moon's orbit go *forwards*, or according to the order of the ſigns.

VI. Becauſe the moon deſcribes an *eccentrical* orbit about the earth at E, *fig.* 13, *pl.* 15, and the action of the ſun upon her ſometimes *increaſes* her tendency towards the earth, and ſometimes *diminiſhes* it, i. e. makes her gravity towards the earth *increaſe*, or *decreaſe*, *too faſt*. If while the moon aſcends from her lower *apſide* A, her gravity towards the earth decreaſeth *too faſt*, inſtead of deſcribing the ſemi-ellipſis A B C, and coming to the *higher apſide* at C, as ſhe would otherwiſe do, ſhe will run out in the curve B F D, and come to the *higher* apſide at F. But the curve A B F D is *more eccentric* than the curve A B C D.

Therefore when the gravity of the moon towards the earth *decreaſes* too faſt, the eccentricity of her orbit will *increaſe*.

On the other hand, if the moon is going from her *higher apſide* C, *fig.* 14, *pl.* 15, to her lower A, and her gravity towards the earth *increaſes too faſt*, inſtead of deſcribing the ſame ellipſis C D A, and ſo coming to the *lower apſide* at A, ſhe will approach nearer to the earth, and deſcribe the curve D F B, and ſo come to the *lower apſide* at F. But the curve C D F B, will be *leſs eccentric* than the curve D A B C.

Therefore, when the gravity of the moon towards the earth *increaſes too faſt*, the *eccentricity* of her orbit will *decreaſe*, and the orbit itſelf will approach nearer to a circle.

Therefore, the *eccentricity* of the moon's orbit will be *continually varying*.

VII. In conſidering the *irregularities* of the moon's motion, we have hitherto ſuppoſed the plane of her orbit as coinciding with the plane of

the *ecliptic*, becauſe her motion would be affected with the irregularities hitherto ſpoken of, if in reality it did ſo.

But it hath been before obſerved, that one half of the moon's orbit A C B, *fig.* 15, *pl.* 15, is raiſed above the plane of the ecliptic A E B G, and the other half A D B *depreſſed* below it; and the *points* A B, where the moon's orbit *croſſeth* the plane of the ecliptic, are called the NODES, and the line A B, joining theſe points, is called the LINE of the NODES.

But when this line of the nodes A B lies in conjunction with the ſun S, it is at *reſt*, but in all other poſitions it goes *backwards*.

When this line of the nodes A B, lies in the *quadrature*, *fig.* 16, *pl.* 15, with the ſun S, it goes *backwards* faſteſt of all.

VIII. It has been formerly obſerved, that the orbit of the moon is *inclined* to the plane of the ecliptic in a certain angle; but this angle is not *conſtantly* the ſame, but ſometimes *greater* and ſometimes *leſs*, depending upon the different poſition of the line of the moon's nodes with reſpect to the ſun.

When the line of the nodes A B, *fig.* 17, *pl.* 15, paſſes through the *ſyzygies*, the plane of the moon's orbit produced paſſes through the center of the ſun S, and conſequently, not being affected by the action of the ſun, is then at it's *greateſt* ſtate, making an angle with the ecliptic of about 5 degrees, 18 minutes.

When the line of the moon's nodes A B, *fig.* 18, *pl.* 15, lies in a quadrature with the ſun S, then, ſuppoſing the line A B C D to repreſent the plane of the *ecliptic*, and A E B F the orbit of the *moon*, let the moon be ſuppoſed to have juſt now paſſed the *aſcending* node at A, and going to her *conjunction* with the ſun at E.

The

The moon will then be going farther and farther from the plane of the ecliptic A B C D, and was there no action of the ſun, would come in conjunction with him at E.

But, becauſe of the action of the ſun, the moon, in going from the *quadrature* at A, towards her conjunction, will be perpetually *drawn down* towards the ecliptic, and therefore will not come to a conjunction with the ſun at E, but at G, making an angle with the ecliptic G A C leſs than E A C.

But the ſun continuing ſtill to act, after the moon has arrived at her conjunction, will go on to *draw* her *down* towards the ecliptic; by which means, ſhe will not croſs the *ecliptic* at the point B, her *former node*, but in ſome other point nearer to the ſun, as K.

But wherever the moon croſſes the *ecliptic* is her *node*. Therefore, her node, in the mean time, hath gone *backward* from B to K, *fig.* 19, *pl.* 15, and the moon hath deſcribed a ſemi-orbit A G K, making a *leſs* angle with the ecliptic, than the orbit A E B, which ſhe would have deſcribed had there been no action of the ſun at all.

CONCLUSION.

Ariſtotle concludes his treatiſe *de mundo*, with obſerving, that "to treat of the world without ſaying any thing of it's author would be impious," as there is nothing we meet with more frequently and conſtantly in nature, than the traces of an all-governing Deity.

The philoſopher who neglects theſe traces, and contents himſelf with the *appearances* only of the material univerſe, and the *mechanical laws of motion*, neglects what is *moſt excellent*; and prefers what is imperfect to what is ſupremely perfect,

finitude to infinity, what is narrow and weak to what is unlimited and almighty, and what is perishing to what endures for ever. Thofe who do not attend to the manifeft indications of *fupreme wifdom* and *goodnefs* perpetually appearing before them, wherever they turn their views or inquiries, too much refemble thofe ancient philofophers, who made *night*, *matter*, and *chaos*, the original of all things.

The plain argument for the exiftence of the Deity obvious to all, and carrying with it irrefiftible conviction, is from the evident contrivance and fitnefs of things for one another, which we meet with throughout all parts of the univerfe. There is no need of nice or fubtle reafonings in this matter; a manifeft contrivance immediately fuggefts a contriver. It ftrikes us like a fenfation; artful reafonings againft it may puzzle us, but it is without fhaking our belief.

No perfon, for inftance, that knows the principle of optics, and the ftructure of the eye, can believe that it was formed without fkill in that fcience; or that the ear was formed without the knowledge of founds; or that male and female in animals were not formed for each other, and for continuing the fpecies. All our accounts of nature are replete with inftances of this kind.

The admirable and beautiful ftructure of things for final caufes, exalts our idea of the contriver; the *unity* of the defign fhews him to be *one;* revelation, that this one is *Jefus Chrift*. The great motions in the fyftem performed with the fame facility as the leaft, fuggeft his *almighty power*, which gave motion to the earth and the celeftial bodies, with equal eafe as to the minuteft particles. The fubtilty of the motions and actions in the internal parts of bodies, fhews that his *influence* penetrates the inmoft receffes of things, and is every where exerted.

exerted. The ſimplicity of the laws that prevail in the univerſe, the excellent diſpoſitions of things, in order to obtain the beſt ends, and the beauty which adorns the works of nature, far ſuperior to any thing in art, ſuggeſt his conſummate *wiſdom*. The uſefulneſs of the whole ſcheme, ſo well contrived for the intelligent beings that enjoy it, with the internal diſpoſitions and moral ſtructure in thoſe beings themſelves, ſhew his unbounded *goodneſs*.

Theſe are arguments which are ſufficiently open to the views and capacities of the unlearned, while at the ſame time they acquire new ſtrength and luſtre from the diſcoveries of the learned. GOD acting and interpoſing in the univerſe, ſhews that he *governed* it, as well as that he formed it; and the depth of his counſels, even in conducting the material univerſe, of which a great part ſurpaſſes our knowledge, keeps up an inward veneration and awe of this great Being, and diſpoſes us to receive what may be otherwiſe revealed to us concerning him.

It has been juſtly obſerved, that ſome of the laws of nature now known to us, muſt have eſcaped us if we had wanted the ſenſe of ſight. God can beſtow upon us other ſenſes of which we have at preſent no idea, without which it may be impoſſible for us to know all his works, or to have more adequate ideas of his nature. In our preſent ſtate we know enough to be convinced of our dependency on him, and of the duty we owe to him as the Lord and diſpoſer of all things.

Though the power of GOD is manifeſted in all his works, it is in the heavens that it ſtill ſeems to beam forth in it's greateſt luſtre. By his power acting there, he directs the courſes of the planets, determines the circumſtances of their motions, and fixes the times of their revolutions. As a General at the head of an army, HE gives the ſignal to the heavenly bodies, and immediately they ſhoot forth,

and proceed in their proper orbits. It is in conſequence of the laws laid down by HIM, that the moon goes round the earth in a month. It is HE that has combined the two motions of the earth, one by which we obtain the viciſſitudes of day and night; the other by which the ſeaſons of the year are brought about. HE it is, who, at the appointed times, ſends ſalutary winds, and fruitful rains and dews; who gathers together the waters in their ſources, and cauſes them to flow from thence in the beds of rivers, to their great receptacle the ſea. It is HE who makes the buds to open, the fruits to ripen, and animals to be prolific, ordering all things according to their different nature, regulating their birth, their growth, and their diſſolution.

Though the Author of ſo many wonders be inviſible, you cannot on that account deny his power, or doubt his exiſtence. You cannot ſee your ſoul, yet the effects it produces in you and around you, are ſenſible proofs of it's exiſtence. It is the ſame with many of the operations in nature. In like manner, GOD alſo, though inviſible in himſelf, is viſible in all his works, and in them appears equally ſtrong in power, admirable in wiſdom, eternal in duration, and ſupreme in perfection.

The whole univerſe conſpires to celebrate his praiſe, from whom it derives all it's majeſty and beauty. The ſun that ſhines in brightneſs, declares the ineffable ſplendor of it's *almighty creator*. The moon and ſtars proclaim to an underſtanding heart, the adorable power of the hand that guides them. The earth, ſo richly ſtocked with productions of higher and lower rank, with the various kinds of vegetable and animal life, paint in the ſtrongeſt terms, the riches of the divine nature,

from

from whom iſſues all that adorns the earth, improves the mind, and delights the ſenſes; governing all things with infinite wiſdom, goodneſs unlimited, power uncontrouled.

That a Divine Mind preſides over and governs the univerſe, is indeed the natural concluſion drawn by *common reaſon*, from the evidence of *common ſenſe*. For who that ſees *this univerſal frame thus wondrous fair*, but muſt infer the *cauſe* of it to be full of wondrous beauty? Who, that obſerves ever ſo ſlightly that *conſtancy* which is in the motions of the planets, and in the riſings and ſettings of the fixed ſtars, &c. can poſſibly imagine the *inconſtancy* of *chance* to be the *mover?* What man, not *diſordered* in his own mind, can ſuppoſe any other thing than *mind* to be the cauſe of that *everlaſting order*, which appears in the regular interchanges of the elements, and the circling returns of the ſucceſſive ſeaſons.

As far as I have conducted you through various branches of natural philoſophy; as far as I have proceeded in giving you a general view of the ſyſtem of the world, *beauty* has every where ſtruck your eye, and engaged you to proceed and ſcrutinize further the operations in nature. The more accurate your ſcrutiny, the more you will diſcover of *regularity*, *ſymmetry*, and *order*, in the conſtitution of nature's frame; the further you penetrate into her deep receſſes, dividing and ſubdividing, opening and unfolding, the minuteſt part of every viſible form, the ſtill more you will find of *beauty within beauty*, and find every order to contain a variety of other orders.

When you ſee the ſun arrayed in glory, and the grandeur of it's departing beams!

When you view the gilded clouds, and the tint of the evening brighter than vermillion!

When you ſurvey the ſtarry concave of

heaven, glittering with the brightneſs of innumerable worlds!

When you ſee the pale moon alſo, ariſing and diffuſing it's ſolemn light over the face of the earth!

Are you not filled with reverence? can you refrain from lifting up your ſoul unto it's maker?

How great is the creator of all theſe things, yea how powerful and good!

O Lord God; all that is in heaven and in earth is thine, and thou upholdeſt all.

Adored by thy name, for ever and ever: and be thou, O moſt mighty, glorified in all thy works.*

* King's Hymns to the Supreme Being.

LECTURE

LECTURE XLVI.

Of Electricity.

MR. STILLINGFLEET has well obſerved, that if the whole ſcene of nature were laid open to our view, were we permitted to behold the connections and dependencies of every thing on every other, and to trace the œconomy of nature through the ſmaller, as well as the greater parts of this globe, we ſhould probably find, that the *great architect* had contrived his works in ſuch a manner, that we cannot properly be ſaid to be unconcerned in any one of them; and therefore, thoſe ſtudies, which ſeem upon a ſlight view to be quite uſeleſs, may in the end appear of no ſmall importance to mankind.

If you look back into the hiſtory of arts and ſciences, you will be convinced, that men are apt to judge too haſtily of things of this nature; you will there find, that he who gave curioſity to his creature, man, gave it for good and great purpoſes; and that he rewards with uſeful diſcoveries what in the firſt inſtance are condemned as trifling or minute reſearches.

But it is true, that theſe diſcoveries are not always made by the ſearcher, or his cotemporaries, or ſometimes even by the immediate ſucceeding generation; but there can be no doubt, but what advantages of one kind or other always accrue to mankind from an inveſtigation of the operations in nature. Some men are born to obſerve and record, what perhaps by itſelf is perfectly uſeleſs, but yet of great importance to another who follows and goes a ſtep further, ſtill as uſeleſs to him; another ſucceeds and

and thus by degrees, till at laſt one of ſuperior genius comes, who laying all that has been done before his time together, brings on a new face of things, improves, adorns, exalts human ſociety.

All thoſe ſpeculations concerning *lines* and *numbers* ſo ardently purſued, ſo exquiſitely conducted by the *Grecians*, what did they aim at? what did they produce for ages? A little arithmetic, and the firſt elements of geometry, were all they had need of. This Plato aſſerts; and though, as being himſelf an able mathematician, and remarkably fond of thoſe ſciences, he recommends the ſtudy of them, yet he makes uſe of motives that have no relation to the common purpoſes of life.

When *Kepler*, from a blind and ſtrong impulſe, merely to find analogies in nature, diſcovered that famous law between the diſtance of the ſeveral planets from the ſun, and the periods in which they complete their revolutions, of what importance was it to him or to the world?

Again, when *Galileo*, puſhed on by the ſame irreſiſtible curioſity, found out the law by which bodies fall to the earth, did he, or could he foreſee that any good could come from his ingenious theorems? or was there any immediate uſe made of them?

Yet had not the *Greeks* puſhed their abſtract ſpeculations ſo far; had not *Kepler* and *Galileo* made the above-mentioned diſcoveries, we never could have ſeen the greateſt work that ever came from the hands of man, *Sir Iſaac Newton's Principia.*

Some obſcure perſon, whoſe name is not ſo much as known, diverting himſelf idly (as a ſtander by would have thought) with trying experiments on a ſeemingly contemptible piece of *ſtone*, found out a guide for mariners on the ocean, and ſuch a guide,

guide, as *no science*, however subtil and sublime it's speculations may be however wonderful it's conclusions, could ever have attained. It is the same with *electricity*. Who could have supposed, on seeing a person amusing himself with the effect of excited *amber* on light bodies, that this was one of the first links in a science that should teach men how to disarm the clouds of lightning, divest the storm of it's terrors, and give life and power to the animal frame.

Other instances might be produced to prove, that bare curiosity in one age, is the source of the greatest utility in another; and what has been frequently said of the chemists, may, perhaps, be applied to every other kind of virtuosi. They hunt, perhaps, after chimeras and impossibilities, and find something really valuable by the bye. We are but instruments under THE SUPREME DIRECTOR, and do not know in many cases, what is of most importance for us to search after; but we may be sure of one thing, that if we study and follow nature, whatever paths we are led into, we shall at last arrive at something valuable to ourselves and others, but of what kind, we must be content to be ignorant.

The nature of aqueous vapours, of fire, and the electrical fluid, will clearly prove to you, that a number of substances may act in nature without being known to us, and that it is our ignorance of their existence, which envelopes in obscurity so many phenomena.

If it were not for the visible diminution of water when it's surface is exposed, and for the hygroscopical appearances, we should not have known that aqueous vapours existed in the atmosphere. Notwithstanding all these phenomena, there are still those who do not admit their existence. It is not difficult, however, to shew that the effects produced

by

by this fluid, while in an imperceptible ſtate, are incomparably greater than the immediate ſymptoms of it's exiſtence.

Again, without *heat*, an effect which is only produced by *fire* when it is diſengaged or free, we ſhould have been ignorant of the exiſtence of fire: yet how great and various are the effects it produces in the combined or latent ſtate! Heat is a ſymptom of the preſence of this fluid, and of it's degree of denſity, when *free* and diſengaged; but if you ſeek to follow it in the phenomena of nature, you find that when it eſcapes from obſervation, it is acting the moſt important of parts. It is the ſame with *light*, the companion of *fire*. If it were not for the impreſſion it makes upon our eyes, we ſhould be ignorant of the greateſt and moſt immediate agent of all terreſtrial phenomena.

Thus you ſee, that there are ſubſtances of the greateſt importance for modifying thoſe which are more groſsly perceptible, and of which, in the mean time, we have little or no knowledge, though they are producing the greateſt effects.

But ſtill further, the *motions* and *light* occaſioned by the *electrical fluid*, when it's natural equilibrium is diſturbed, are the *only ſigns* which give us notice of it's exiſtence. All *electrical* phenomena concur in proving the exiſtence of a *certain fluid*, poſſeſſed of certain characters, capable of particular modifications, and diſſeminated over the whole ſurface of the globe; the *why* or *wherefore* is ſtill unknown, we are ſtill ignorant of it's functions. But we are at the ſame time ignorant of the cauſe of ſo many phenomena in nature, that we ought not to deſpair of being able to diſcover thoſe with which it is connected, and how it influences them by it's compoſition and decompoſition.

It

It refults from the obfervations I have now made, that the known *expanfible fluids* have two kinds of properties; one whereby they *manifeft* themfelves to one or more of our fenfes, the other by which they act *imperceptibly* in a number of phenomena. It is not then neceffary, as a proof of the exiftence of a fubftance, nor of it's being a principal agent in phenomena, that it fhould be manifefted to our fenfes. But it is *effential* in nature, as foon as you confider *phyfical* objects, that to every *phenomenon* there be a *caufe;* and the only method of affigning a reafonable one, where they are not immediately difcoverable, is *analogy*. When therefore certain phenomena, whofe caufe is hidden, are analogous to other phenomena that we attribute to the intervention of fome *fubftance*, we are naturally led to fome *fubftance* as a caufe of the firft mentioned phenomena; and nothing will oppofe their admiffion, if they explain what cannot be explained without, and if there is nothing which renders the exiftence of the fubftance obfcure.

Here I cannot refrain from obferving, that the French philofophers, after extending the influence of electricity over all nature, now pafs it by as if unworthy of notice; it's name is not even to be found "dans le tableau de la *nouvelle nomenclature!*"

Philofophy owes much to the affiftance it has received from mathematicians; but this only happens when they apply themfelves to the ftudy of phenomena; when neglecting thefe, calculations are made to ferve an hypothefis; the more elegant and beautiful they are, the more detrimental they become to fcience. It is thus, that Æpinus, by a mathematical theory of electricity, has clofed the door on all our refearches into the nature and operations of this fluid.

ELECTRICAL APPEARANCES.

From these preliminary obſervations, which I conſidered as neceſſary to excite your attention to the electric fluid, and to lead you to look out for, and to trace it's connection with other agents in nature; I ſhall proceed to point out ſome of the moſt ſtriking electrical appearances. The knowledge obtained of electricity, like moſt other articles of ſcience, has riſen from very ſmall beginnings, and by very ſlow degrees to it's preſent height. It had been known for ages, that *amber, jett,* and other bodies, would, upon rubbing, attract and repel light bodies, as hairs, feathers, down, duſt, &c. and as this property was moſt conſpicuous in *amber,* which in the Greek is called *electron,* the peculiar power of that body was termed *electricity.* Upon further inquiry, it was found, that not amber only, but ſeveral other ſubſtances had the ſame properties in a high degree; that *glaſs, reſinous ſubſtances, ſilk, dry wood,* &c. have the ſame properties; and that any of theſe, when dry, and rubbed for a ſhort time, would attract light ſubſtances.

I rub this ſtick of *ſealing-wax* with ſoft flannel, and you ſee it attracts any light ſubſtances, as hairs, feathers, &c. that I bring under it; rub a *glaſs tube* with dry ſilk, and you will find it produce the ſame effect. Let us now darken the room, rub the glaſs tube again, and you will ſee *ſparks of fire* follow your hand; preſent your knuckle to the tube, and theſe ſparks will be formed into pencils or bruſhes of light, attended with a crackling noiſe like that of a green leaf in the fire.

The friction has, in theſe inſtances, manifeſted to the ſenſes the *exiſtence* of a ſubſtance that was before imperceptible. The body, that is made by friction to exhibit theſe appearances, is ſaid to be

be excited. The appearances are termed *ſigns of electricity*.

Here is a fine downy feather tied to a *ſilk* ſtring; I electrify it ſtrongly, by touching it with the excited *glaſs tube*, and it immediately flies from, or is repelled by the glaſs tube. I now preſent an excited ſtick of *ſealing-wax*, and the feather immediately flies towards it. Thus you ſee, that what is *attracted* by excited *wax*, is repelled by excited *glaſs*. This experiment gave riſe to a very important diſtinction in electricity, implying a *contrariety* of *agency* therein, and one power or agent was denominated *vitreous*, the other *reſinous* electricity. Further diſcoveries ſhewed, that glaſs or wax would, according to the circumſtances in which they were ſituated, produce either power.

Our two next experiments lead alſo to another very important diſtinction in this branch of ſcience. I ſuſpend a *braſs* ball by a *wire* from the end of the glaſs tube oppoſite to my hand, and excite the tube as before; as ſoon as the tube is excited, you will find that the ball has acquired all the electric properties of the tube; it will, like it, attract light bodies, and give the ſpark. Let us now ſuſpend the ball by a *ſilk* ſtring, and excite the tube as before; you may now rub as long as you pleaſe, but the ball will exhibit no ſigns of electricity. Here then we have two ſubſtances, through one of which, the *wire*, the electric properties may be conveyed; whereas the other, that is, the *ſilk*, prevents their paſſing to the ball. The *wire* is therefore called a *conductor* of electricity. The ſilk is termed a *non-conductor*.

Or in more general terms, all thoſe bodies, through which the electrical fluid is tranſmitted freely, are termed *conductors*. Thoſe bodies, through which it does not paſs ſo freely, are called *non-conductors*.

A body

A body resting entirely upon non-conductors is said to be *insulated*. Thus in the last experiment, the ball was *insulated*, because it was suspended by a *silk string*, which is a non-conductor. Insulation prevents the dissipation of the electrical appearances.

THE PRINCIPLES OF ELECTRICITY DEDUCED FROM EXPERIMENTS ON ATTRACTION AND REPULSION.

I have already shewn you, that a light body electrified by excited *glass*, is *repelled* thereby, but will be *attracted* by excited *wax*; and that, on the other hand, if it be electrified by excited *wax*, it will be repelled thereby, but will be attracted by excited *glass*. This observation you must keep in mind, without it you can never understand the operations of electricity. The greater part of the experiments in this science, and the whole of the reasonings thereon, depend on a reference to these facts.

For the following experiments, I make use of light balls formed out of the pith of elder; they are suspended by fine linen threads from small cylinders of wood, and are insulated upon a common wine glass, that is dry, free from dust, fibres of down, &c.

I electrify two balls, thus suspended, by excited *glass*, and you see they *repel* each other. I destroy this electricity by touching them with my hand. I again electrify them, but with excited wax, and they again *repel* each other. I bring the balls electrified by wax towards those electrified by glass, and they immediately fly towards each other.

From these experiments you will infer, 1. That bodies electrified vitreously, repel each other. 2. That bodies electrified resinously, repel each

each other. 3. That bodies electrified with contrary powers, attract each other.

As those light substances which possess the same electric power *repel* each other, it will always be easy for you to *discover with what power they are electrified*. If they are *repelled* by excited glass, they possess the vitreous electricity; if they are attracted thereby, they are resinously electrified; on the contrary, those attracted by excited wax, are vitreously, and those repelled thereby, resinously electrified. In ascertaining the nature of the electric power, you must avoid bringing the bodies to be tried near each other suddenly; or one strongly electrified too near one that is weakly, so as it may render the experiment doubtful, for reasons that will soon be apparent.

Before I go any further, it may be proper to point out to you the leading feature of that theory of electricity, (Mr. Eeles's) * which I adopt in these Lectures. I consider, with him, all those electrical operations that are manifested to the senses, as occasioned by *two distinct*, *positive*, and *active* powers, which equally and strongly *attract* and *condense* each other; but when by any circumstance they are rendered unequal to each other, the *increased* power *expands* into an atmosphere.

These two powers *exist together* in all bodies; in their natural state they are always *conjoined*; the electric

* See "Eeles's Philosophical Essays in several letters to the Royal Society, London, 1771." On a comparison of this work with the greater part of the modern writers on electricity, you will find that they have been gradually giving up the most essential distinctions of the Franklinian theory, and adopting those of Mr. Eeles. See Wilson, Henly, Gray, Milner, Brooke, Peart, Read, &c. &c. And you will find him laying down principles, and making experiments, that have within a few years been brought forwards as new; some have indeed been rejected at first, because deemed contradictory to a favourite theory, but which have since been fully acknowledged.

electric signs, or what we call *electricity*, are only rendered sensible to us by the separation of these powers. In other words, though the *electric matter* is acting the most important part among the operations in nature, in it's united, and to us *latent* and *invisible* state, yet it becomes no object to our senses, till it's powers are separated and rendered unequal.

When the powers are separated and brought into action, the increased power expands, and forms what may be termed an electrical atmosphere. If any body be immerged in this atmosphere, the powers thereof are separated, and that which is of the same kind with the atmosphere is repelled, while the contrary power is attracted: as long as the body remains immerged therein, the powers remain separated. It is however to be observed, that in exciting electrics, the powers are never entirely separated. The diminished power acts *inward* to the electric, while the increased power acts *outward* with an extensive atmosphere.

I hold excited glass over this cylinder, *fig.* 1, *pl.* 16, but at a certain distance from it (which distance will depend upon the power of the glass); it repels the vitreous electricity of the tube into the balls, which will diverge with vitreous electricity, and will of course recede from excited glass. I remove the excited glass from over the balls, and they close. A temporary separation of the electric matter *inherent* in the cylinder, is in this instance produced by the influence of the excited glass; as soon as this influence is removed, the powers unite, and the balls close.

I now place two cylinders, with their ends in contact with each other, *fig.* 2, *pl.* 1, and hold the excited tube over the end A; each pair of balls diverge. While they are in this state, separate them

them one from the other, and you will find the balls of A to be vitreoufly electrified, and thofe of B refinoufly fo; proving, that while the body remained immerged in the atmofphere, the electric powers thereof were feparated, *one being at each end.* Bring the tubes together again, and the balls immediately *clofe;* proving, 1. That the feparated powers attract each other. 2. That when united, they condenfe each other, and that all electric figns are immediately loft. 3. The *co-exiftence* of the two powers in the cylinders.

Again electrify the balls equally, but with the fame powers, then bring the ends of the cylinders together, and the divergence of the balls will not be altered; which fhews, that equal atmofpheres of the fame kind do not act on each other.

Hold an excited glafs tube over the cylinder, *fig.* 4, *pl.* 1, and at the fame time keep one of your fingers in contact with the oppofite end of the cylinder, remove the glafs tube and finger together, and the balls will diverge with refinous electricity; for on trying, you will find them *fly towards* excited *wax*, and *recede from* excited *glafs.* The vitreous power is repelled by the excited tube, and paffes into the finger, which, in exchange, communicates refinous electricity to the cylinder.

The tendency of an electric atmofphere to produce the contrary electricity, in the bodies contiguous to it, is pleafingly illuftrated by the following experiment. In this, there are four cylinders, A, B, C, D, *fig.* 3, *pl.* 1; excited glafs held over A, repels the vitreous power into B, and draws the refinous into A; in the fame manner, B repels the vitreous power of C into D, and draws the refinous into C; feparate B and D from A and C, juft before the excited glafs is removed, and you will find A and C poffeffing the refinous, B and D the vi-

treous electricity; as you will find by bringing the excited glafs towards the balls, thofe at A and C will move towards the glafs, thofe at B and D will recede from it.

You faw in a former experiment, where the balls were equally electrified with contrary powers, that on bringing the cylinders together, the powers united, and all electrical figns vanifhed. But if one be electrified more than the other, that which is leaft fo, lofes all it's electricity after contact, and the two remain electrified, with the excefs of the electricity of that which was ftrongeft.

From thefe experiments it appears, that the *increafed* power expands itfelf, and acts *outwards*, and that in proportion to the fubtraction of the other power; and that it is this fphere of the expanded power, which is called an electric atmofphere.

It appears further, that no fubftance feems to be electrified, while the powers are equal in or on that body; but in proportion as there is a greater quantity of one power, than there is of the other, then the increafed power acts outwards from that body, and the body will be electrified with that power, and will repel any other body electrified with the fame power; but will attract any fubftance electrified with the contrary power; and after contact between them, all electrical figns vanifh, if they were equally electrified; but if unequally, both will remain electrified with the excefs of the ftrongeft power.

Thefe pofitions will be confirmed by other experiments, in which you will fee the contrary directions of the two powers.

OF

Of the Electrical Machine, and it's Mode of Action.

By turning the handle of the machine, and of course the glaſs cylinder which moves with it, electricity is produced; and this we ſhall find, as before, of *two* kinds, each ſtrongly attractive of the other, though repulſive of a ſimilar kind; when united, the expanſive power they before exerted, is condenſed, and all electric ſigns vaniſh.

To render theſe poſitions clear, I inſert a wire in the cuſhion, and another in the conductor; each of theſe is furniſhed with a braſs ball at top, and each of them has a ſliding wire with balls on it's end, that it may be ſet at any convenient diſtance from the other. On turning the cylinder, you obſerve, 1. That I can obtain an electric ſpark from the balls of either wire on preſenting my knuckle thereto. 2. That a ſtrong ſpark will paſs from one ball to the other. 3. That on holding a cork ball ſuſpended by ſilk, between the two braſs balls, it is alternately attracted and repelled from one to the other. 4. Electrify a pair of inſulated balls by the cuſhion, and you will find them to poſſeſs the *reſinous* electricity; electrify them by the conductor, and they will poſſeſs the *vitreous* power. 5. Join the balls together, and all electric ſigns vaniſh.

On the other hand, if you place both wires either on the conductor, or the cuſhion, you will find that no ſpark will paſs between them, that the cork ball remains ſtationary, being neither attracted nor repelled by the balls, and this becauſe they both poſſeſs the ſame kind of electricity.

From theſe experiments we infer, that the *conductor* and the *cuſhion* are electrified with different powers; that one attracts what the other repels, and that when they are united, they exhibit *no ſigns* of electricity; that on the ſeparation of the

powers by excitation, *one* power attaches itſelf to the excited *electric*, the *other* to the *rubber*.

The whole variety of electrical experiments appear to be nothing more than different modes of deſtroying or reſtoring an equilibrium. By deſtroying the equilibrium, *two poſitive powers* are at the ſame time produced. By reſtoring the equilibrium, all things return to their natural ſtate, and every appearance of electricity ceaſes. The two powers are ſo connected, that one can never be exhibited without producing the other. It is probable, that in the general operations of nature, this fluid always acts in it's united form, that in which it is to our ſenſes *latent* and *inviſible*.

On turning the cylinder and ſeparating it from the ſilk, the electric powers are ſeparated, the cylinder gives it's reſinous power to the cuſhion in exchange for the vitreous; the conductor in like manner exchanges it's powers with the cylinder; for as long as the cuſhion communicates with the table by a chain, and you continue turning the cylinder, you will find the conductor ſtrongly electrified with the *vitreous* power. Take the chain from the cuſhion, and ſuſpend it from the conductor; on turning the cylinder you will find the cuſhion ſtrongly electrified with the *reſinous* power. Connect the cuſhion and conductor by a chain, and the powers reunite almoſt as ſoon as they are ſeparated, and the electrical ſigns *diſappear*.

We now ſee why *conducting ſubſtances cannot be electrified unleſs they are inſulated.* It is becauſe the two powers join inſtantaneouſly in the nonconductor, and ca. therefore exert no ſenſible action.

When I turn the cylinder ſlowly, only a ſmall quantity of the fluid is excited, and it does not fly far in the form of a ſpark; but when I turn ſomewhat faſter, and make the black ſilk adhere to the glaſs, the quantity of excited electricity is conſiderably increaſed. The flaſh or ſpark paſſes through

through a greater ſpace, and aſſumes a crooked or zig-zag direction, reſembling the flaſhes of lightning. The brilliancy of the ſpark depends much on the preſſure of the atmoſphere; for the ſpark which explodes in *air* is vivid like lightning; but if the ſame be tried in *an exhauſted receiver*, inſtead of a ſpark and exploſion, you have only a *ſilent*, *faint*, diluted ſtream.

Before I proceed to other experiments, I ſhall explain your machine more fully, and ſhew you how to excite it powerfully. The parts of the machine, which fall more immediately under your attention, are, 1. The *electric*, or the glaſs cylinder which is to be excited. 2. The *mechanical contrivances* by which it is put in motion. 3. The *cuſhion* and it's appendages. 4. The *conductor*, or conductors.

The glaſs cylinder of the machine before you, *fig.* 5, *pl.* 1, is put in motion by a ſimple winch. This is leſs liable to be out of order, than thoſe that are turned with a multiplying wheel, and will alſo enable you to excite the machine more powerfully. The cylinder, F G H I, is ſupported by two ſtrong perpendicular pieces, D E. The axis of one cap of the cylinder moves in a ſmall hole at the upper part of one of the ſupports. The oppoſite axis paſſes through the upper part of the other ſupport. To this axis the winch or handle is fitted. The cuſhion is ſupported and *inſulated* by a glaſs pillar; the lower part of this pillar is fitted into a wooden ſocket, to which a regulating ſcrew is adapted, to increaſe or diminiſh the preſſure of the cuſhion againſt the cylinder. A piece of ſilk comes from the under edge of the cuſhion, and lies on the cylinder, paſſing between it and the cuſhion, and proceeding till it nearly meets the collecting points of the conductor. The more ſtrongly this ſilk is made to adhere to the cylinder, the ſtronger is the de-

gree of excitation. Before the cylinder, or opposite to the cushion, is a metallic tube Y Z, supported by a glass pillar L M. This is sometimes called the *prime conductor*, often only the *conductor*. For the more convenient trying experiments on the two powers, and exhibiting the different states of the cushion and conductor, there are two wires to be fixed occasionally, the one to the conductor, the other to the cushion; on the upper part of these, are balls furnished with sliding wires, that they may be set at various distances from each other.

Before the electrical machine is put in motion, examine those parts which are liable to wear either from the friction of one surface against another, or to be injured by the dirt, that may insinuate itself between the rubbing surfaces. If any grating or disagreeable noise is heard, the place from whence it proceeds, must be discovered, wiped clean, and rubbed over with a small quantity of tallow; a little sweet oil or tallow should also be occasionally applied to the axis of the cylinder.

The screws that belong to the frame should be examined, and if they are loose, they should be tightened.

The different working parts of the machine having been looked into, and put in order, the glass cylinder, and the pillars which support the cushion and conductor, should be carefully wiped with a dry old silk handkerchief, to free them from the moisture which glass attracts from the air, being particularly attentive to leave no moisture on the ends of the cylinder, as any damp on these parts carries off the electric fluid, and lessens the force of the machine: in very damp weather it will be proper to dry the whole machine, by placing it before, but also at some distance from, the fire.

Take

Take care that no duſt, looſe threads, or filaments, adhere to the cylinder, it's frame, the conductors, or their inſulating pillars; becauſe theſe will gradually diſſipate the electric fluid, and prevent the machine from acting powerfully.

Rub the glaſs cylinder firſt with a clean, coarſe, dry, warm cloth, or a piece of waſh leather, and then with a piece of dry, warm, ſoft ſilk; do the ſame to all the glaſs inſulating pillars of the machine and apparatus; theſe pillars muſt be rubbed more lightly than the cylinder, becauſe they are varniſhed.

A hot iron may in ſome caſes be placed on the foot of the conductor, to evaporate the moiſture which would otherwiſe injure the experiments.

To excite your machine, clean the cylinder, and wipe the ſilk.

Greaſe the cylinder by turning it againſt a greaſy leather, till it is uniformly obſcured. The tallow of a candle may be uſed.

Turn the cylinder till the ſilk flap has wiped off ſo much of the greaſe, as to render it ſemi-tranſparent.

Put ſome amalgam on a piece of leather, and ſpread it well, ſo that it may be uniformly bright; apply this againſt the turning cylinder, the friction will immediately increaſe, and the leather muſt not be removed until it ceaſes to become greater.

Remove the leather, and the action of the machine will be very ſtrong.

The preſſure of the cuſhion cannot be too ſmall, when the excitation is properly made.

The amalgam is that of Dr. Higgins, compoſed of zinc and mercury; if a little mercury be added to melted zinc, it renders it eaſily pulverable, and more mercury may be added to the powder, to make a very ſoft amalgam. It is apt to cryſtallize by repoſe, which ſeems in ſome meaſure

to

to be prevented by triturating it with a ſmall proportion of greaſe: and it is always of advantage to triturate it before uſing.

A very ſtrong excitation may be produced by applying the amalgamed leather to a clean cylinder, with a clean ſilk; but it ſoon goes off, and is not ſo ſtrong as the foregoing, which laſts ſeveral days.

OF THE MOMENTUM OF THE ELECTRICAL FLUID.

The great ſtrength and velocity diſplayed by the electrical fluid in it's motions, is an object well worthy your inveſtigation: and if it be granted, (and I think I ſhall be able to prove it to you) that the electric matter is the ſame with the *ſolar fluid*, then will the *ultimate* cauſe of it's momentum be the power by which the light of the ſun is propagated, the preſſure of which being equal all round upon all bodies, it can neither move them one way nor the other. But if by means of any other power, this preſſure is leſſened upon any particular part, the current of matter will ſet forwards towards that place, with a force proportioned to the diminution of the preſſure. Thus, in the common experiments of the air-pump, when the air is exhauſted from the receiver, the preſſure of the ſuperincumbent atmoſphere is directed towards every part of the glaſs, ſo that if it be of a flat ſquare ſhape and not very ſtrong, it will certainly be broken. Now there is reaſon to ſuppoſe, that after the air is exhauſted from the receiver, it is full of another ſubtil fluid of the ſame nature with the electric. If this could alſo be extracted from the receiver, the preſſure on it's ſides would be much greater, becauſe not only the atmoſphere, but the whole ſurrounding ether, would urge towards that place; and it is not probable, that

that this preſſure could be reſiſted by any force whatſoever.

The momentum, therefore, of the electrical fluid depends on two cauſes, *the preſſure of the atmoſphere* upon the electric matter, and *the preſſure of one part of this matter upon another*, which is extended throughout the immenſity of ſpace. The force and velocity of the fluid depends, therefore, in a great meaſure, on that which ſurrounds us. There is a certain ſtate of this fluid, that we violate by our experiments; when this violation is ſmall, the powers of nature operate gently in reſtoring the diſorder we have introduced; but when any conſiderable deviation is occaſioned, the ſame powers reſtore the original conſtitution with extreme violence.

EXPERIMENTS ON ELECTRICAL ATTRACTION AND REPULSION.

To the top of this wire, three large downy feathers are affixed by three linen threads. I inſert the lower end of the wire into the prime conductor; upon turning the cylinder, the plumage expands every way, the threads alſo recede as far as poſſible from each other. If I place my fingers near the feathers, all the plumulæ bend towards it; if I move my finger this way or that, they all move after it as if alive; I put my hand on the conductor, immediately the threads loſe their divergence, the plumulæ collapſe, and fall cloſe together; I take my hand away, the threads diverge, and the feathers expand as before.

I cannot explain to you the mechaniſm which occaſions the threads to diverge; but I can ſtate thoſe facts which muſt concur to occaſion it. We know that thoſe light bodies which poſſeſs the ſame kind of electricity ſeparate from, or repel each

each other ; the finger communicates to them the *contrary power;* towards this, therefore, they are impelled by thier nature, in order to reſtore an equilibrium which our operations have deſtroyed. By putting my hand on the conductor, the powers are immediately exchanged and united, and the electrical effects ceaſe.

I place this cork ball, ſuſpended by ſilk, ſo that it may be even with the conductor, and at about ſix inches from it. I turn the machine, but the cork remains quiet; touch it with the end of the wire in your hand, and the *vitreous* power of the ball is driven into you, and an equal quantity of the *reſinous* is communicated to the ball, which, will then therefore fly with great rapidity towards the conductor ; direct the pointed end of the wire towards the ball, and it will keep it fixed to the conductor, by continually ſupplying it with the reſinous power; remove the wire, and the ball parting with it's reſinous power to the conductor, in exchange for the vitreous, of which the conductor has the greateſt quantity, it becomes electrified therewith, and repelled from the conductor.

Analagous to the foregoing experiment is the following, with a piece of linen thread, which from the vivacity of it's motions, is termed the *animated thread.* For this purpoſe I preſent a fine thread towards the electrified conductor, and it will fly backwards and forwards, in a very pleaſing manner, according as it conveys the vitreous power to the hand, or the reſinous to the conductor, to which it will ſometimes be affixed, for the ſame reaſon as the ball in the preceding experiment. Let a thread hang from the conductor, and preſent another towards it, they will attract and join each other: preſent any non-conducting ſubſtance, as a braſs ball, near the two threads ; the lower one, or that held by the hand, will fly *from* the

the ball, while that affixed to the conductor flies *towards* it. The vitreous atmoſphere of the conductor repels the vitreous power of the ball into the hand, and draws the reſinous power into it; the ball being therefore reſinouſly electrified, attracts the upper thread, but repels the lower one, which is in the ſame ſtate with itſelf, as acted on by the ſame cauſes. In this experiment the *afflux* and *efflux* of the two powers is, as it were, viſible to the ſenſes. You will find, *that a contrariety of power muſt always precede, and is abſolutely neceſſary to all electrical attraction*, and indeed to every communication of electricity.

I ſuſpend a ſmall copper plate from the conductor; underneath this, and at a ſmall diſtance from it, is a larger copper plate which reſts upon a proper ſtand; on the lower plate I put a leaf of gold; turn the cylinder, the leaf riſes upon the plate, and expands itſelf into a perfect plane, with one corner oppoſite the upper, the other corner oppoſite the under plate, moving quickly upwards and downwards between both; I lower the under plate by degrees, the motion of the leaf has now ceaſed, and it remains ſuſpended in the air between the two plates; darken the room, and you will find the leaf ſupported, as it were, by pillars of fire; now as no ſubſtance can be thus ſupported in equilibrio, but by the joint action of two forces acting in oppoſite directions, we have a clear proof that there muſt be two forces thus acting in the preſent inſtance.

Place ſome ſmall paper figures of men, women, &c. on the lower plate, *fig.* 7, *pl.* 1; turn the cylinder, and you ſee the images riſe up, moving from one plate to the other. They generally move in an erect poſition, ſometimes leaping one upon another, and moving in ſuch a variety of poſtures, as to afford much entertainment. The dance between them has ſo droll an appearance, if well conducted, that there are few

who

who can look upon it without laughing. I have before obſerved to you, that there are *two powers* in electricity; now the heads of the puppets are electrified with one power, and the feet with the other; they are therefore repelled at both ends, and never come in contact, unleſs the lower part of one touch the higher part of the other, and then they approach and ſtick together.

The foregoing experiment is not only amuſing, but inſtructive: you will find that a very minute alteration in their figure, will make the images dance between the plates, or remain fixed to the upper or under plate; for this end, the upper part ſhould be always ſo much larger than the lower part, as to contain a part of the power going in, as much greater than what goes out, as will be equal to the gravity of the paper: with a little practice you will be able to make one of them dance for ſome minutes without touching either the top or bottom plate.

To further illuſtrate the affluence and effluence of the two powers, dry the head of one of the images, and the power thrown out from the conductor cannot enter that puppet ſo freely, as the contrary power from the lower plate enters the feet, which are not ſo dry; the image will therefore aſcend to the upper plate, and remain there; reverſe the experiment, by drying the feet and wetting the head, and the image will remain fixed to the lower plate. Theſe as well as many other experiments will prove to you, *that it is not the mere component parts of the body that are acted on, in electrical experiments*, but that it is the different *ſtates* of the electrical powers inherent or adheſive to the body which occaſion the effects; and that, ſtrictly ſpeaking, it is the oppoſite powers only that attract each other, and that no ſubſtance is ever attracted until it has acquired a contrary electricity.

If the two powers cannot be put in action, the experi-

experiment will not ſucceed; for if you place your images on a clean dry pane of glaſs, and hold this under the upper plate (firſt removing the lower plate and it's ſtand), you will find, that the images will not be put in motion, notwithſtanding you continue to turn the machine. Glaſs does not tranſmit the two electricities, and therefore no contrariety in the electric ſtate of the image can be occaſioned, and conſequently it will not move backwards nor forwards between the two plates. But if any means be uſed to cauſe an exchange in the powers, as by holding your finger under the glaſs plate, they will be driven backwards and forwards as before.

Here is a ſmall apparatus, conſiſting of three bells with two clappers between them, *fig.* 6, *pl.* I; they are ſuſpended from a ſtrait piece of braſs, the two outer ones by ſmall braſs chains, the middle bell and the clappers are ſuſpended on ſilk; from the middle bell there is a chain which goes down to the table; I turn the machine, and the clappers fly from bell to bell, affording you a pleaſing peal by electricity. The power from the conductor is conveyed down the chains to the exterior bells; by means of the chain, the exterior bells repel the ſame power with which they are electrified from the ball or clapper, which, on the powers being thus ſeparated, are driven to the outer bell by the contrary power which ſits in from the table, &c. through the middle bell; the ball becoming electrified with the ſame power as the middle bell, is driven back, and will continue going from one to the other, as long as the outſide bells are kept in an electrified ſtate by the machine.

If you take hold of the ſilk cord which is tied to the lower end of the chain that comes from the middle bell, and thereby raiſe that chain from the table, the ringing will immediately ſtop; for ſilk being

being a non-conductor, prevents the *afflux* and *efflux* of the fluids.

As the apparent attraction and repulsion of all light bodies depend on the *afflux* and *efflux of the separated powers*, I shall not, in shewing you every experiment, enter into a detail of these circumstances; hoping that what I have already said, will render that point sufficiently clear. I turn the machine with one hand, and hold the other about three or four inches from the end of the conductor; drop a small lock of cotton upon the hand near the conductor, and the cotton immediately jumps from my hand to the conductor and back again, stretching itself out both ways into a longish form, and moving so quick that you will scarce be able to perceive it's form.

Here is a small toy, somewhat resembling a hog; I have coated it with ermine, in the hairs of which I have inserted a few pieces of cotton pulled out, so as to be of a considerable length; place this upon the conductor, I turn the machine, and the hairs of the ermine diverge, and the pieces of cotton are discharged and driven some feet from the conductor. This apparatus, by thus discharging it's quills, may be called with propriety the *electrical porcupine.* *

Few branches of philosophy afford so much entertainment as electricity; here the useful and the agreeable are intimately blended, and while you are investigating science, you are entertained by the variety and beauty of the experiments. It was the strong, attractive, and repulsive powers exhibited by electricity, that first engaged the attention of natural philosophers; by these they were led on to pursue the subjects, as it were by enchantment,

* Communicated by Mr. Wiffet.

ment, and have been richly rewarded by diſcoveries both intereſting and important.

A few more of the leading experiments, which have been ſo advantageous to ſcience, will not be unpleaſant.

METHODS OF IMITATING THE PLANETARY MOTIONS.

Rackſtrow's orrery conſiſts of ſmall glaſs balls blown exceeding thin; they are placed on a wooden board, and environed with circles of braſs wire inſulated with ſealing-wax, or glaſs, of ſuch a height that the center of the balls may be nearly parallel to the wire circles. One of theſe circles may repreſent the orbit of *Saturn*, another that of *Jupiter*, &c. the circles being connected with the conductor of the machine by a wire, and a glaſs ſphere placed between each, the ſpheres will perform *their revolutions round their orbits*, and at the ſame time acquire *a rotation on their axes*.

When the machine is ſet in motion, the balls will be firſt attracted to the braſs circles, by which means the point that touches the braſs circle will become electrified, and be immediately repelled; other parts will in the ſame manner be attracted and repelled, by which means the glaſs ball acquires a kind of ſpinning motion on it's axis, at the ſame time it muſt have a progreſſive motion round the circle.

Provide a ball of cork about three quarters of an inch in diameter, hollowed out in the internal part by cutting it in two hemiſpheres, ſcooping out the inſides, and then joining them together with paſte. Having attached this to a ſilk thread, between three and four feet in length, ſuſpend it in ſuch a manner that it may juſt touch the knob of

an electric jar, the outside of which communicates with the ground. On the first contact it will be repelled to a considerable distance, and after making several vibrations, will remain stationary; but if a candle is placed at some distance behind it, so that the ball may be between it and the bottle, the ball will instantly begin to move, and will turn round the knob of the jar, moving in a kind of ellipsis, as long as there is any electricity in the bottle. This experiment is very striking, though the motions are far from being regular; but it is remarkable, that they always affect the elliptical rather than the circular form.

Cut a piece of India paper in the shape of an isosceles triangle, whose sides are about two inches long and two tenths of an inch in breadth; then erect a brass ball of two or three inches diameter on a brass wire one sixth of an inch in thickness, and two feet six inches long, on the prime conductor; electrify the conductor, and then bring the obtuse end of the piece of paper within the atmosphere of the ball; let it go, and it will revolve round the ball, turning often round it's own axis at the same time.

TUMBLER AND BALLS.

Put a pointed wire into one of the holes which are at the end of the conductor, hold a glass tumbler over the point, then electrify the conductor and turn the tumbler round, that the whole interior surface may receive the fluid from the point; place a few pith balls on the table, and cover them with this glass tumbler, the balls will immediately begin to leap up and down, as if they were animated, and will continue to move for a long time.

ELEC-

ELECTRICAL FLUID UNIVERSALLY DISSEMINATED, AND IN CONTINUAL ACTION.

That the *electrical fluid is universally dissemi-nated*, and in continual action, has long been the opinion of those who have paid attention to it. To prove this to others, various instruments have been contrived to detect the *smallest* variations, and discover the minutest signs of it's existence; these have been generally named *electrometers*; and among these, that described by the Rev. Mr. BENNET, of Wirksworth, stands the foremost, as being by far more sensible than any of the rest.---This is one of them, *fig.* 1, *pl.* 2.

The foot is made of metal, and about three inches high, that you may handle the instrument without touching the glass; the cylindrical glass, in which the gold leaf is suspended, is about five inches high, and one in diameter; the cap is made of metal, and flat on the top, that the various substances whose electricity is to be examined may be conveniently placed thereon. The diameter of the cap is larger than that of the glass, and it's rim is about an inch deep, hanging parallel to the glass, in order to keep it clean and dry; within this is another circular rim that goes over the glass, and is lined with a soft substance to make it fit close, within this rim; at the center of the cap a tube is fixed, wherein the peg is placed to which the two slips of gold leaf or silver are fastened.

If there were no glass, the gold leaf would be so agitated by the least motion of the air, that it would be entirely useless. To prevent the gold leaf from being attracted and torn by flying to the glass, two pieces of tinfoil are fastened, with varnish on the opposite sides of the glass, where it may be expected to strike these slips and carry off the super-

fluous

fluous electricity, and increaſe the ſenſibility of the inſtrument.

The experiments made with this inſtrument, not only ſhew that the electrical fluid is univerſally diſſeminated, but that the *ſmalleſt motions* in nature *diſturb* it's natural equilibrium, and *ſeparate* the two powers, and thus manifeſt it to our ſenſes. That this fluid is the etherial medium, or element of fire, connected with ſome material ſubſtance, can ſcarce now be doubted: if ſo, all the oſcillations in nature put it in action, or, what is more probable, it is the cauſe of thoſe oſcillations. Mr. BENNET's electrometer will prove to you, that all *ſolution of continuity* excites electricity; and I believe there is ſcarce any inſtance where it's *action is manifeſted*, but what may be *traced to this ſource*. In other words, every thing that will increaſe one power, or leſſen the other, *produces electric ſigns*.

Not to interrupt too much the progreſs of our Lectures, I ſhall relate to you ſome of Mr. BENNET's experiments.

1. Powdered chalk was put into a bellows, and blown upon the cap of the electrometer; the ſtream of chalk produced vitreous electricity, when the nozzel of the bellows was only ſix inches diſtant from the cap; but the ſame ſtream electrified it with the reſinous power, when at the diſtance of three feet. In this experiment the quality of the electricity ſeems to be changed by diſperſing or widening the ſtream, and making it paſs through a longer tract of air; it is alſo changed by paſſing the ſtream through a bunch of fine wires, ſilks, or feathers, placed in the bellows; it is reſinous when blown from a pair of bellows, the iron pipe being taken off to enlarge the ſtream. This laſt experiment ſeems to anſwer beſt in damp weather. The vitreous electricity generally remains; but in the reſinous, the leaf

leaf gold collapſes as ſoon as the cloud of chalk is paſſed.

2. A piece of chalk drawn over a bruſh, or powdered chalk put into a bruſh, and projected on the cover, gave reſinous electricity. The electricity was not permanent.

3. Powdered chalk blown with the mouth, or a pair of bellows, from a plate placed upon the cover, gave a permanent vitreous electricity. If a bruſh is placed upon the cover, and a piece of chalk is drawn over it, when the hand is withdrawn, the leaf gold gradually expands with vitreous electricity, as the cloud of chalk diſperſes.

Of the Franklinian Theory.

It was not my intention at firſt to have particularly noticed the defects of this theory; but as ſome late writers have endeavoured to conceal it's errors, either by giving up ſome of the moſt eſſential parts, or by endeavouring to bend facts to accommodate to this theory, it became neceſſary to point out a few of it's defects and inconſiſtencies. Many parts thereof, I conceive, would never have been accredited, if it had not been neceſſary for party purpoſes, to eſtabliſh the author's reputation as a philoſopher.*

From hence we may learn, that all new diſcoveries ſhould be admitted with caution, for they are ſeldom accurate, and free from errors; we are too often apt to be led away by glimmerings of light, or even falſe views of objects, which are often of worſe conſequences than a total want of knowledge.

 I ſhall

* On this head, the anecdotes to be related are numerous and curious.

I ſhall enumerate the leading principles of the Franklinian ſyſtem, thoſe which have always been conſidered in that light, by the beſt writers, and ableſt advocates in favour of this ſyſtem; and we may therefore juſtly conclude, that whoſoever gives up any of theſe, ſo far abandons the principles on which it is founded.

1. That the *operations* of electricity depend on the action of a *ſimple homogeneous* fluid.

2. That the electric matter violently *repels* itſelf, but attracts all other matter.

3. That *glaſs* and all other electrics, though they contain a great quantity of electric matter, are nevertheleſs *impermeable* thereto.

4. That by the *excitation* of an electric, the equilibrium of the contained fluid is broke, and one body becomes *overloaded* with electricity, while the other is *deprived* of it's natural ſhare.

5. Electricity is *poſitive* when a body has more than it's natural ſhare; the electricity is *negative* when a body has leſs than it's natural ſhare.

With reſpect to the firſt poſition, you will find, that it's friends can bring no experimental proof to ſhew the homogeneity of this fluid, or it's actions; but on the contrary, they are forced by experiment to acknowledge a contrariety of ſtate in every operation.

The ſecond poſition is not only deſtitute of proof, but contradictory to all experiments; for the electric fluid never *attracts matter* as ſuch, but only on account of the ſtate of the electric matter therein. It is not repulſive of itſelf; the appearances on which this idea is grounded, are owing to the reſiſtance of the air. Both attraction and repulſion ceaſe where the powers can unite without this reſiſtance.

In the courſe of theſe Lectures, you will ſee many experiments that prove the permeability of glaſs,

glaſs. The notion of it's impermeability is altogether hypothetical, for it is not ſupported by any one determinate experiment, and is contrary to every electrical appearance. You will find the ideas of the Franklinians concerning it quite contradictory, ſome allowing that it's influence acts through glaſs, yet maintaining that it is impermeable thereto; others allowing certain kinds of glaſs to be permeable. Indeed you may gather from their writings, that the *beſt*, and the *worſt vitrified glaſs*, that *cold* and *warm* glaſs are all more or leſs permeable.*

The fourth and fifth principles may be conſidered as one, for they are ſo intimately connected, as not to be ſeparated: whatever weakens the proofs of the one, diminiſhes thoſe of the other. The whole Franklinian hypotheſis falls to the ground, if the ſupporters thereof cannot prove, that *poſitive* electricity is a ſuperabundant quantity, an accumulation of electric matter in the body poſitively electrified, and *negative* electricity a deprivation of the quantity of this matter natural to a body.

Now in the firſt place, we have ſtrong reaſon to ſuppoſe, that every electric appearance is occaſioned by the fluid being in a divided and weakened ſtate; but putting this conſideration out of the queſtion, let us aſk the ſupporters of the Franklinian ſyſtem for a proof of this poſition, and (ſtrange to tell!) you will find it deſtitute thereof. You will find them only reaſoning in a circle, proving the thing from itſelf; a method from which no concluſion can be drawn. Thus, for inſtance, a body that is poſitively electrified, attracts

* Lyons, Remarks on the leading Proofs of the Franklinian Theory. Milner's Experiments and Obſervations on Electricity, &c. &c.

one that is negatively electrified, becaufe the firft has too much, and the other too little electricity. Demand how they prove one has too much, and the other too little of this fluid, and they anfwer, becaufe they attract each other ! ! !

According to their principles, the electrical fluid is as active when *redundant*, as when *deficient*; and yet when it is in an *intermediate* ftate, it is inactive. "Two light bodies fufpended in contact, in their *natural* ftate fhew no figns of electricity; *take away* part of their electric fluid, and they repel each other; take away ftill more, and the power of repulfion increafes; fo that the more a body is *deprived* of it's electric fluid, the more *active* and *extenfive* is it's electric action." *

Another mode by which they endeavour to fupport their fyftem is, by fhewing that the electric fluid always moves in one direction, that is, from the pofitive to the negative. Now if it can be proved, as I think it has already been in a great degree, that there are *two powers acting in contrary directions*; the negative electricity will turn out to be a *pofitive active power*, and the Franklinian hypothefis will fall to the ground, being deftitute of any proof. I fhall hereafter fhew you, that in the difcharge of the Leyden phial, there is not only a power acting from the infide to the outfide, but alfo at the fame inftant a power acting from the outfide to the infide. Whofoever allows two currents acting in oppofite directions, whatever may be his pretences, gives up the Franklinian theory, and confeffes himfelf unable to maintain it on the original principles laid down by the author, and vindicated by Canton, Le Roy, Prieftley, Becket, Henly, Beccaria, Cavallo, &c. &c.

Further proofs of the inconfiftency and weaknefs of this theory will be fhewn in the courfe of

thefe

* Peart on Electric Atmofpheres.

theſe Lectures; but they are ſo numerous, that to expoſe them all, would occupy too much of our time; one or two more I ſhall mention here; thus you will find Dr. Gray, in the Philoſophical Tranſactions, proving Dr. Franklin's account of the charge and diſcharge of the Leyden jar, to be erroneous; yet endeavouring to ſupport the weakeſt part thereof. Mr. Brooke, in his "Miſcellaneous Experiments," has ſhewn, (what *Mr. Ecles* had ſhewn years before, and that by reaſoning *a priori* from his theory) contrary to the ideas of the beſt judges and friends of Franklin's theory, that during the time of charging a Leyden jar, both inſide and outſide have the ſame kind of electricity. Mr. Read has demonſtrably proved, (by a method previouſly pointed out by *Mr. Ecles*) that in the diſcharge of the Leyden phial, a vacuum forming a part of the circuit, the electric matter moves in contrary directions; yet ſuch is the force of philoſophic authority, that both Mr. Brooke and Mr. Read endeavour to bend theſe facts to ſupport a theory, with which they are utterly irreconcileable.

Of the Electric Spark, and of the Influence of Points.

I bring the knuckle of my hand near the conductor, and a ſpark with the appearance of fire paſſes between the conductor and my hand, and I feel a ſenſation ſomewhat reſembling a ſtroke from the end of a ſmall wire. I remove my knuckle further from the conductor, and the ſpark is longer, forming ſeveral curves in it's paſſage, having the exact appearance of a flaſh of lightning. In this experiment as much of one power paſſes from the finger to the conductor, as of the other from the conductor to the finger. No ſpark will paſs unleſs there can be this interchange of power; and

and the ſpark is always from thoſe parts where the exchange can be moſt readily effected.

Where the two powers can be eaſily changed, which is the caſe with *pointed* metallic bodies, the equilibrium is reſtored *ſilently*, and the conductor is of courſe gradually diveſted of it's electric appearances: but where the ſurface is large, and a contrary ſtate not ſo eaſily produced, the electricities are as it were compreſſed, and do not eſcape till they have acquired power to overcome the intervening ſpace of air, when it *explodes*, and the *ſpark is vivid like lightning*.

As ſoon as I preſent a needle, or any other fine pointed ſubſtance, to an electrified body, the electric fluid is urged there with great velocity, and the electricity is ſaid to be drawn off. *This drawing off, however, does not extend to any great diſtance*, not even all round the electrified body, if you keep turning the machine at the ſame time that you preſent the point. To prove this, place the wire, to the end of which a number of fine threads are faſtened, in one of the holes on the top of the conductor; turn the machine, the threads on the wire diverge, and ſpread out like rays proceeding from a center; now preſent a point towards one ſide of the conductor, but at ſome diſtance from it, and you ſee the threads on one ſide loſe their divergence and hang down, while thoſe on the other ſide continue to diverge.

Indeed a point *never acts beyond the electric atmoſphere*, nor does it act upon that any further than it is immerged therein, and then only ſo far as it *can draw the reſinous power through them, and part with ſo much of the vitreous to them.* Suſpend a piece of down, or a ſmall ball, by ſilk, ſo that it may hang againſt the ſide of the conductor; when you turn the machine, it will be electrified,

electrified, and fly to the extreme part of the conductor's atmoſphere; now ſtop turning, and bring a point towards the outſide of the down, and inſtead of the down being driven in towards the conductor, it will fly to the point, till it has exchanged powers with the point; then it will fly to the conductor, and be electrified, and again repelled; when it comes to a certain diſtance from the point, it will fly towards it, and be electrified thereby, and ſo on, as long as the conductor remains electrified.

When the down is on the verge of the electric atmoſphere, immerge your point in the atmoſphere, and you will ſee the down approach the conductor in proportion to the immerſion of the point, and this as often as you move the point forward to the conductor, but no further; ſo that the point acts only while in contact with the electric atmoſphere.

While the machine is turning, and the point immerged in the electric atmoſphere, there is a ſtrong ſtream of the reſinous power flowing in from the point to the conductor, and that in proportion to the vitreous power carried off by the point. If this ſtream meets an electrified cork ball, or piece of down, it will change their powers, and electrify them with the reſinous power, by which means they are attracted to the conductor, and will be fixed there by the continual ſtream of the reſinous power; draw back your hand to leſſen the reſinous ſtream, and you will ſee the down move from the conductor by degrees, and remain between the two powers, without being forced to the conductor, or able to fly far therefrom. The foregoing experiments are moſt deciſive with a weak electricity.

That the ſpark or paſſage of the electrical fluid, from the prime conductor to any conducting ſubſtance, depends upon the greater or leſs degree of

of difficulty in producing the contrary current, is further evinced by placing a point at the end of a piece of ſealing-wax, and at a ſmall diſtance from that part of the metal in contact with the ſealing-wax, paſte a ſmall round bit of tin-foil, at a little diſtance from this another bit, &c.; put your finger upon one of the pieces of tin-foil, that is furtheſt from the metallic point, and preſent the point towards the conductor, and you will find that it does not act near ſo powerfully, nor at ſo great a diſtance as in the former caſe; and if you approach it ſufficiently near the conductor, a ſpark will paſs between it and the conductor. Connect your finger immediately with the metal, and you will not be able toobtain a ſp ark, and the electric appearances of the conductor will be ſooner deſtroyed by the quicker interchange of the contrary powers.

As the ſpark, which explodes, and is bright in the *air*, becomes ſilent, faint, and diluted in *vacuo*; ſo, on the other hand, the electricity, that would paſs *imperceptibly* in air, may be made to explode, and become bright, by paſſing it through mediums more reſiſting than air.

I place a metallic veſſel nearly filled with common oil on the conductor; I ſhall immerge therein a point, from which, in the open air, I can ſcarcely obtain any viſible appearance, and you ſee that under theſe circumſtances, *ſtrong ſparks paſs between the point* and the bottom of the veſſel, and the oil is thrown into a violent ebullition, by the afflux and efflux of the two electricities.

Here is a pointed wire ſuſpended vertically from the conductor, the point being downwards, from which I can obtain no ſpark, though the machine is acting powerfully. I immerge it in a ſmall bottle of oil, and put my thumb oppoſite the point; the ſpark is loud, the oil is curiouſly agitat-

ed,

ed, and if you examine the bottle, you will find it perforated.

Round this glafs tube, *fig.* 2, *pl.* 2, at fmall but equal diftances from each other, pieces of tin-foil are pafted in a fpiral form, (hence it is called the *fpiral tube*) from end to end; this tube is inclofed in a larger one, fitted with brafs caps at each end, which are connected with the tin-foil of the inner tube. Hold one end in the hand, and apply the other near enough to the prime conductor to take fparks from it, a beautiful and lucid fpot will then be feen at each feparation of the tin-foil; thefe multiply, as it were, the fpark taken from the conductor; for if there was no break in the tin-foil, the electric fire would pafs off unperceived.

Here are feveral fpiral tubes, *fig.* 4, *pl.* 2, placed round a board, a glafs pillar is fixed to the center of the board, on the top of this pillar is a brafs cap, carrying a fine fteel point, to fupport a wire furnifhed at each end with a brafs ball, and nicely ballanced. I place this under a ball proceeding from the conductor, fo that a continued fpark from this ball to the center of the fufpended wire, gives this wire a rotatory motion, and the balls in their revolution will give a fpark to each fpiral tube, which, in it's paffage from one fpot to the other, forms a moft beautiful fpecies of illumination.

Take this piece of *filvered leather*, and put it round your head, and then ftand upon the ftool with glafs feet, connecting yourfelf with the conductor by a chain. If, while I turn the machine, any one pafs their knuckles near the hoop of leather, moving them round it, the leather will be beautifully illuminated, and brifk flafhes of electric lightning will pafs between the knuckles and conductor.

ductor. This experiment has been termed the *diadem of beatification.**

Spirits of wine may be eaſily *fired* by the electric ſpark; to inſure ſucceſs in making the experiment, it is beſt either to heat the metallic ladle into which the ſpirits are to be placed, or elſe juſt to fire the ſpirits, and blow them out, a few ſeconds before they are electrified. This experiment may be performed two ways: 1. By placing the ladle with the ſpirits on the conductor, and then taking a ſpark through the ſpirits, which will ſet them on fire. Or, 2. If a perſon ſtands on the inſulated ſtool, and holds in his hand a ſpoon with the ſpirits of wine, and another perſon on the floor brings his knuckle, or a braſs ball, quickly to the ſurface of the ſpirits, they will be inſtantly in a flame. You may vary this experiment thus: 3. Let the electrified perſon on the ſtool hold the ſpirits as before, while another perſon, ſtanding alſo on an inſulated ſtool, holds in his hand an iron poker, one end of which is made red hot; he may then apply the hot end to the ſpirits, and even immerge it in them, without firing them; but he may ſet the ſpirits on fire, with either the hot or cold end, provided the hot end be not worn to too ſharp a point. The ſpirits could not be kindled while the perſon was inſulated, becauſe the electric powers could not in that caſe be ſeparated; and hot iron, immerſed in ſpirits, will very ſeldom or never ſet them on fire.

You muſt have already obſerved, from what you have ſeen, that when the quantity of electricity is ſmall, it is incapable of ſtriking at a conſiderable diſtance, and the ſpark appears ſtrait; but when it is ſtrong, and capable of ſtriking at a greater diſtance, it aſſumes a crooked ziz-zag direction. In every electrified conductor, the electricity

* For a further variety of experiments on theſe principles, ſee my *Eſſay on Electricity.*

tricity always eſcapes from that part of the ſurface, where the powers are moſt ſeparated. The ſpark is of a different colour according to the denſity; when it is rare, it appears of a bluiſh colour; when more denſe, it is purple; when highly condenſed, it is clear and white like the light of the ſun. The middle part of an electric ſpark, when the two powers meet, often appears diluted, and of a red or violet colour, the ends are more vivid and white; when very ſtrong, it will branch out and divide into many parts.

OF MOTIONS PRODUCED BY THE ELECTRIC STREAM.

Whenever there is an *efflux* of one power of electricity, there is alſo an *afflux* of the other power, if any conducting ſubſtance is placed ſo near and in ſuch circumſtances, as that it can be drawn therefrom.

Here is a braſs croſs, *fig.* 5, *pl.* 2, ſupported on a point like a compaſs needle, with each of it's points bent the ſame way; place this upon the conductor, and as ſoon as I turn the machine, it turns with great rapidity, but always from the points, becauſe the electric fire flying off from the points, acts forcibly on the air, and is conſequently re-acted upon, which occaſions the motion. Take the fly and it's point, and hold it in your hand under the conductor, and it will turn in the ſame manner, by a ſtream of electricity of a contrary power to that thrown off from the conductor, which is drawn in from you and delivered from the points of the fly to the conductor. Now inſulate the fly, and place it at the ſame diſtance from the conductor, and it will not move, becauſe no electricity can be drawn through it; but hold a pin near it, and the fly will immediately begin to turn, as it draws

draws a ſufficient quantity of electricity from you through the pin.

On this principle, thoſe who are deſirous of blending agreeable entertainment with philoſophy, may contrive a variety of curious machines, whoſe motions may be produced by the electrified ſtream, which will afford much entertainment to thoſe who can reliſh domeſtic innocent amuſement; and by theſe ſcience will be benefited, for to render any ſcience familiar, is to render it prevalent, and the more it prevails in practice, the more likely it is to produce uſeful diſcoveries.

If ſmall boats, or little ſwans, &c. are made of cork or light wood, they may be attracted, and made to ſwim in any direction, by applying a finger towards them; a fine needle ſtuck into the end of the boats, in the manner of a bowſprit, will cauſe them to be repelled from the hand held over it, and they may be ſteered by it, ſtern foremoſt, to what point of the compaſs you pleaſe. The boats might have the addition of ſails to them, and might then be made to move briſkly before an electrical gale, from the point of a wire held in the hand.

The operator in theſe tricks would certainly be looked upon as a magician, if the electrical machine is kept out of ſight. But a more ſtriking ſight, would be a number of theſe boats, with each of them a twirling fly, about an inch in length fixed to the top of the maſt; the hand held over them would ſet them all in motion; in the dark they would appear as ſo many rings of fire, moving in various courſes, and following the hand in any direction.*

OF

* Becket on Electricity.

Of the Diffusion and Subdivision of Fluids by Electricity.

From experiments made by Abbé Nollet, it appears, that electricity augments the natural evaporation of moſt fluids, particularly of thoſe which have the greateſt tendency to evaporate; that it, in this reſpect, acts moſt powerfully upon the fluids when they are contained in metal veſſels; but it *never* makes any fluids *evaporate through the pores* either of metal or glaſs. When fluids, that are paſſing through capillary tubes, are electrified, the ſtream is ſubdivided; and if the tube be leſs than $\frac{1}{10}$ of an inch in diameter, their motion is generally accelerated.

I ſuſpend this metal phial (to the bottom of which a capillary tube is adapted) to the conductor; before I turn the cylinder, the tube carries off the water only by interrupted drops; but on turning the cylinder, and electrifying the water, the dropping from the tube is changed into a continued ſtream. On applying my finger to the conductor, the electricity is interrupted, and the water again only deſcends in drops: my finger taken away, the water runs in a diverging ſtream: darken the room, and you perceive a fiery ſtream deſcend from the tube. This experiment has been termed the electrical *jet de feu*.

Inſulate two pails with capillary tubes; connect one with the cuſhion, the other with the conductor; turn the machine, and the water, which is diſperſed into very minute particles, when they are near enough, is brought together by the effort of the two powers to join each other; the drops coaleſce and come down like a heavy ſhower of rain.

I place a drop of water on the conductor, and turn the machine. On preſenting my knuckle to-

 wards

wards this drop, long *zig-zag ſparks* are obtained *from the drop of water;* the drop takes a conical figure; my knuckle is wetted. The ſpark was conſiderably longer than could be obtained from the conductor without the water.

Faſten a piece of good ſealing-wax to the ball on the end of the conductor, but place it in ſuch a manner that it may be eaſily ſet on fire by a taper; ſet it on fire while I turn the machine; the wax becomes pointed, and ſhoots out an *almoſt inviſible* thread to a conſiderable diſtance. If you receive the filaments on a ſheet of paper, the paper will be covered in a very curious manner by the *electrified wax threads;* the wax flying to thoſe places where it can unite with the contrary power.

LECTURE

LECTURE XLVII.

Of the Leyden Phial.

DR. PRIESTLEY has well obſerved, that electricity has one advantage over moſt other branches of natural philoſophy: it furniſhes matter of entertainment for all perſons promiſcuouſly, while it is alſo a ſubject of important ſpeculation for the moſt philoſophic minds. Neither the air-pump, nor the orrery, nor any experiments in hydroſtatics, optics, or magnetiſm, &c. ever brought together ſo many, or ſuch great concourſes of people, as thoſe of electricity have ſingly done.

If you only conſider what it is in objects that makes them capable of exciting that pleaſing aſtoniſhment which has ſuch charms for all mankind, you will not wonder at the eagerneſs with which perſons of both ſexes, and of every age and condition, run to ſee electrical experiments. For here you ſee the courſe of nature overturned to all appearance, and by cauſes ſeemingly inconſiderable.

For it exhibits to you bodies riſing and falling, moving this way and that, and ſuſpended by others contrary to the principles of gravitation, and this by powers which have been put in action only by a very ſlight friction. Here you may ſee a piece of cold metal, or even water or ice, emitting ſtrong ſparks of fire, ſo as to be able to kindle many inflammable ſubſtances. Nor will you find any thing more aſtoniſhing than what I am going to exhibit to you. You will find a common glaſs jar, after a little preparation, capable of giving a perſon ſuch a violent ſenſation, as nothing elſe in nature can give; and that the diſcharge of the bot-

tle is attended with an explosion like thunder, and a flash like lightning.

Before I enter into the theory of charged glass, I shall shew you in what manner it is charged and discharged. This jar is coated on the outside and lined on the inside with tinfoil, to about two inches short of the top, which is stopped with a piece of wood. A wire passes through the wooden top, and is connected underneath with two other wires, which are bent so as to touch the inside coating of the jar; a smooth ball is fixed on the top of the wire.

To discharge the jar without receiving what is called the shock. For this purpose, two instruments have been contrived, one called the *common discharging rod, fig.* 8, *pl.* 1, which is nothing more than a semicircular brass wire, furnished with two brass balls, one at the end of each wire. The other, which is of very extensive use in electrical experiments, is called the *jointed discharging rod, fig.* 9, *pl.* 1; it is furnished with a glass handle; the legs are moveable, and may be set to any given distance by means of the joint.

Place the jar on the table, so that the ball on the top of it's wire may be about one-eighth of an inch from the ball of the prime conductor. Turn the machine, and sparks will fly from the ball of the conductor to the ball of the jar: continue turning as long as you perceive the fire pass between the conductor and ball of the jar; when it ceases, you may leave off turning, and consider the jar as *charged.* This done, take hold of the discharger by the middle, and apply one knob to the outside coating near the bottom, and keeping it there, put the other to the ball of the jar, and it will be *discharged* of it's fire with a loud snap, but the person who holds the discharger feels nothing from the discharge.

Now

Now charge the jar, and touch the outſide coating with one hand, and then bring the other to the ball of the jar, you will then act the part of the wire diſcharger, and receive a ſhock; it has affected you through your arms and breaſt, and the phial is diſcharged. You may eaſily contrive, by way of recreation, to render the ſurpriſe occaſioned by this experiment more entertaining, by connecting a chain with the outſide coating, and concealing it under a carpet, at the ſame time connecting another with the top,* placing it in ſuch a manner, that a perſon may put his hand upon it without ſuſpicion, at the ſame time that his feet are upon the other wire; but great care ſhould be taken that theſe ſhocks are not too ſtrong, and that they be not given to all perſons indiſcriminately.

When a ſingle perſon receives a ſhock, the company is diverted at his ſole expence; but all contribute their ſhare to the entertainment, and all partake of it alike, when the whole company form a circle by joining their hands, the perſon at one extremity of the circle touching the outſide coating, while he, who is at the other extremity touches the ball of the jar. All the perſons who form this circle being ſtruck at the ſame time, and with the ſame degree of force, it is pleaſant to ſee them all ſtart at the ſame moment, to hear them compare their ſenſations, and obſerve the very different accounts they give.

It is often convenient, ſometimes neceſſary, to know the ſtate of a jar with reſpect to the charge; Mr. Henly's *quadrant electrometer* is the beſt inſtrument yet known for that purpoſe. It conſiſts, *fig.* 17, *pl.* 1, of a perpendicular ſtem formed at top like a ball, and furniſhed at it's lower end

 with

* This may be conveniently done by what is called a medical Electrometer.

with a brafs ferril and pin, by which it may be fixed in one of the holes of the conductor, or at the top of a Leyden bottle. To the upper part of the ftem, a graduated ivory femicircle is fixed, about the middle of which is a brafs arm or cock, to fupport the axis of the index. The index confifts of a very flender ftick, which reaches from the center of the graduated arch to the brafs ferril; and to it's lower extremity is faftened a fmall pith ball nicely turned in the lathe. When this electrometer is in a perpendicular pofition, and not electrified, the index hangs parallel to the pillar; but when it is electrified, the index recedes more or lefs according to the quantity of electricity.

OF THE THEORY OF THE LEYDEN BOTTLE.

I fhall now endeavour to explain to you the theory of this myfterious bottle; and you will there fee, that the electric powers, when in equilibrio, do really condenfe each other; and that one power always expands in proportion as the action of the other is withdrawn, or in proportion to the increafe of one power, and the diminution of the other; and that when the bottle is charged, it is *equally electrified* on both fides, but with different powers of electricity; and when a communication is made by a conductor, the increafed power on the outfide flies in, and the increafed power within flies out, to make the powers equal within and without.

Place a Leyden bottle upon the infulated ftand, form a communication between it and the conductor, give the machine a few turns, and *both fides of the bottle will be electrified with the vitreous power*, as you may eafily prove, by touching them with down or a fmall ball fufpended by filk; for when this is electrified by touching the outfide, it will

will be alſo repelled by the ball which communicates with the inſide.

Place an inſulated bottle ſo that the ball may communicate with the conductor; let a wire alſo be connected with the coating, ſo as to form a communication with the table. Now turn the machine, and, 1. On applying a cork ball, you will not find any ſigns of electricity in the coating, but you will find the ball (or inſide) electrified with the vitreous power. 2. Remove the wire communicating with the table, and you will find the *coating* alſo electrified with the *vitreous* power; and this as often as you remove the wire, *till the bottle is full charged.* 3. When the bottle is full charged, remove it's communication both with the conductor and table, touch the coating, and the cork ball will remain ſuſpended by it, without any ſign of being electrified; then touch the knob of the bottle with your hand, the cork ball will be ſtrongly repelled from the coating, and be electrified with the reſinous power. 4. Take another cork ball ſuſpended by ſilk, and touch the knob of the bottle therewith, and the cork ball will be electrified with the vitreous power and repelled. 5. Now touch the coating with your finger, and the cork ball will be repelled much further by the ball; but that which was repelled from the coating, now flies towards it, and remains at reſt, till you touch the knob of the bottle with your finger; it will then be electrified as at firſt, and be violently repelled; the ball which was electrified by the knob of the bottle will now fly towards it. This change in the extent of the atmoſphere of the different powers, takes place almoſt inſtantaneouſly as often as you touch the ball or coating.

Or you may connect the knob of the bottle with the conductor by a wire, and ſuſpend a cork ball to

touch the conductor; then touch the coating, and the ball will be repelled from the conductor, while that next the coating is attracted; touch the knob of the bottle, and the ball will be repelled from the coating, and attracted by the conductor, and so on, as often as you touch the knob or coating.

From hence it seems plainly to appear, 1. That the bottle is electrified with the vitreous power on the inside, and the resinous on the outside. 2. That when the equilibrium of these powers is destroyed by lessening the quantity of one, the extreme part of the other expands itself into an extensive atmosphere; but the atmosphere of the lessened power is condensed, as appears by the cork balls falling close to the conductor and coating. 3. It remains to be shewn, how these powers came to be thus situated on the inside and outside of the bottle, or why they do not mix through the glass where they seem to have the greatest tendency to unite. Here it will be necessary to consider the separation of these powers between the globe and the cushion, for all the other phenomena are only a consequence of the separation that takes place between these. Now the cylinder parts with it's resinous power to the cushion, in exchange for the vitreous; the conductor in like manner to the globe, and the inside of the bottle to the conductor; and so the exchange would go on with the next conducting substance, but that the bottle gives some obstruction to the passage of the electrical powers; by which means the vitreous power, which passes through the glass to the conducting substance upon the outside of the bottle, is carried off together with the vitreous power of the coating, along the wire which communicates with the table, in exchange for an equal quantity of the resinous power brought back by the wire to the coating of the bottle; till at length the resinous

power

power on the outside is able to counterballance the vitreous power on the inside, and thus affords an opportunity for drawing off the resinous power on the inside of the bottle, to the conductor; so that the bottle remains a partition between the two powers, and they cannot change place through the peculiarly constructed pores of the glass, while their surfaces are opposed in such quantities.

For when the junction is made in the open air, or when their surfaces are opposed in any quantity, it is not done without violence, occasioning a loud noise and a flash of fire, while bursting through to meet each other; for wherever the different powers unite in any quantity, they are much condensed.

The violent convulsion felt through the body by completing a circle with the hands, is only occasioned by the different powers passing in opposition through the same *nerves*. For if one person touches the coating, and another the top of the bottle, the bottle will be discharged without giving either of them the shock. Now it is very clear, that as much fire passed through either of them, as if each had singly discharged the bottle. But in this case the fire is diffused through all parts of the body, and the fire brought in, is drawn from all parts of the body, and consequently the nerve cannot be so much shocked as in the former case, when all the fire passes in opposition through the same nerves.

EXPERIMENTS ILLUSTRATING THE THEORY OF THE LEYDEN PHIAL.

Charge an insulated bottle, remove it from the conductor, and let a cork ball suspended by silk hang against the outside of the bottle; touch the outside or coating with your finger, the ball will

will not be affected; but touch the knob of the bottle, and the ball immediately flies off, strongly electrified with the resinous power; and thus you may go on for a considerable time, altering the ballance of the powers within and without side the bottle, by alternately touching the top and the bottom of the bottle. The defenders of Franklin's system will hardly say, it is the return of the positive electricity which electrifies the ball negatively. The fact is, that when you touch the top, you take a spark of the vitreous power from the inside, and in exchange, give as much of the resinous power thereto; by this means, the force of the vitreous power within the bottle is lessened, which leaves the resinous power on the outside in greater quantity, than the vitreous within side, and consequently at liberty to exchange with any non-electric in contact with it, and thus the ball becomes electrified with the resinous power.

Charge a bottle fully, and remove the wire from the table, and make the coating communicate with the conductor instead of the knob, and then turn the machine, and the resinous power with which the coating is electrified becomes covered with the vitreous power, and you may take as many sparks from it as you please, without making any change in the charge of the bottle; for when you stop turning, and remove the communication with the conductor, and touch the outside of the coating with the finger, all signs of the vitreous power disappear; and when the circle is completed, the bottle is discharged with as loud a report as it would have done before you applied the conductor to the coating; for the vitreous power within the bottle being undisturbed, kept an equal quantity of the resinous power firmly fixed to the outside of the bottle.

But the case is different when you give the vitreous

vitreous power from the inſide an opportunity to eſcape. Thus when the bottle is full charged as before, remove the wire that communicates with the table, and bring the coating in connection with the conductor; after a turn or two of the cylinder, take a ſpark from the ball of the bottle, and you will find that it will fly to a conſiderable diſtance, often double the diſtance you can draw a ſpark from the conductor, becauſe the vitreous power covering the reſinous power on the coating, leſſens the action on the vitreous power within the bottle, and therefore leaves that power greater freedom to fly off; but as you go on taking ſparks, they gradually leſſen, becauſe after a few, the vitreous power in the bottle is leſſened, and the reſinous power within increaſed by the quantity received in exchange on every ſpark; and thus by a few ſparks, the bottle is diſcharged; but if you go on to take more ſparks, the bottle will be re-charged with the reſinous power withinſide, inſtead of the vitreous, with which it was before charged.

Again, ſuppoſe fifty turns of the cylinder will charge your bottle, turn only twenty-five, and then remove the communication between the coating and table, and as you *turn on*, (whether you continue the communication from the conductor to the top of the bottle, or ſhift it to the coating,) you will find the bottle electrified *on both ſides with the vitreous power*; remove the bottle from the conductor, and then diſcharge it with an inſulated diſcharger, and you will find the bottle ſtill electrified, *both within and without*, *with the vitreous power*; but this electricity will diſappear, by touching either the ball or coating with your finger.

To illuſtrate further the reciprocal exchange of the electric powers, here is an inſulated bottle with a wire proceeding from the bottom, at right angles

gles to which is a wire for receiving a needle with reversed points; make the top of the bottle communicate with the conductor, and *all the time the bottle is charging*, the needle will turn; but when the bottle is charged, the needle stops. Then touch the top of the bottle with your finger, or any conductor, and the needle will turn till the bottle is discharged. Now while the bottle is charging, if you touch the needle with a piece of bog-down, or a cork ball, suspended by silk, you will find it electrified by the *vitreous power*, which flies off in exchange for the resinous power drawn in from the air to the outside of the bottle; and while the bottle is discharging, if you apply the down or ball in the same manner to the needle, you will find them electrified with the *resinous* power, which flies off from the outside of the bottle in exchange for the vitreous power drawn in through the points from the air; while the vitreous power from the inside of the bottle makes the same exchange for the resinous power through your finger, to make these different powers equal to each other, withinside and withoutside the bottle.

Place two Leyden bottles on an electric stand, with their coatings in contact; and while you charge one from the conductor, let a person on the floor touch the top of the other bottle with his finger; you will find the first bottle charged with the vitreous power inside, and the second with the resinous power inside. Now the exchange here is evident; for while the resinous power from the inside of the first bottle changes place with the vitreous thrown in from the conductor, the vitreous, from the coating, changes place for so much of the resinous from the coating of the second bottle; and the vitreous in that bottle changes place for so much of the resinous power drawn in through the man on the floor.

I charge a Leyden phial, and set it aside to be in

in readineſs to aſcertain the ſtate of another. I now take the bottle with the projecting wires, *fig.* 10, *pl.* 1, unſcrewing the ball from the wire at the coating, and ſuſpending a pair of pith balls therefrom. This done, I bring the knob of the bottle to the conductor; I work the machine, and the phial will charge ſlowly, and the balls will repel each other; *while I am turning and the bottle charging*, bring the knob of the firſt bottle towards the balls, and they will be repelled thereby. This plainly proves, that the outſide of the bottle is *electrified vitreouſly while it is charging*, that is, with the ſame electricity as the inſide.

Let us diſcharge the bottle with the projecting wires, and charge it again as before, and you will ſtill find, that *whilſt it is charging*, the balls will fly from the knob of the firſt bottle; I *ceaſe* turning, and the balls ceaſe to repel each other; they now touch each other, and again recede, but with a contrary electricity, for they are now attracted by the knob of the firſt bottle. This ſhews that the difference between the two ſides cannot appear, while they are charging, or while vitreous electricity is forced through the jar.

Let us now diſcharge both bottles, in order to try another experiment, to determine the ſtate of the outſide during the charge. I firſt put the ball on the end of the wire of the bottle with the projecting wires, bring the knob thereof to the conductor, holding the knob of the firſt bottle againſt the coating of that with the projecting wires; by working the machine, both will be charged. As ſoon as they are pretty well charged, and *while the machine is working*, remove the firſt bottle from the other; after this is removed, ceaſe working the machine as ſoon as poſſible. I now connect, by a wire, the two outſide coatings, and bring the balls to each other. If, while the bottles were charging,

ing, the outside of that with projecting wires had been resinously electrified, the inside of the second would have been so also; and on their being thus brought together, both bottles would be discharged; but this is not the case, for the insides of both are charged with the vitreous electricity, the coating having exchanged powers with the bottle charged thereby. This experiment shews, that to consider one side of a phial to be *positive*, and the other *negative*, *at the time they are charging*, is erroneous.

The criterion of the resinous and vitreous electricity, as determined by the light on metallic points, gives full evidence in favour of Mr. Eeles's theory, while it is directly opposed to that of Dr. Franklin. For you will here find, that during the time that the bottle is charging, the outside exhibits the sign of vitreous electricity. To prove this, I place a pointed wire at the end of the conductor, and place this apparatus, with the sliding wires, *fig.* 11, *pl.* 1, on one of the insulated stands, first removing the bottle therefrom; I then unscrew the balls from the projecting wires of the remaining insulated bottle, and also from the sliding wire, which leaves the points, that were under the bottle, exposed and ready for our operations.

Things being thus prepared, I place the insulated bottle, so that the point, from the inside, may be about half an inch distance from that in the conductor, and let one of the points of the sliding wire be at the same distance from, and opposite to, the point projecting from the outside of the insulated bottle. I now turn the machine, and as soon as the charge begins, the signs of the electricities are visible, illuminating the points of the interrupted circuit. The point on the prime conductor gives the brush or sign of vitreous electricity; the sign on the point opposed to it on the knob of the bottle is resinous. The light

from

from the wire, that projects from the coating of the bottle, is the brush or vitreous ramified light; but that of the point opposed thereto, is the star, or sign of resinous electricity, as they ought to be according to Mr. Eeles's theory, not "contrary to the kind or source of electricity from whence they proceed," which is the case, on the principles of the Franklinian theory.*

EXPERIMENTS SHEWING THAT IN THE DISCHARGE OF THE LEYDEN JAR, THE TWO ELECTRICITIES RUSH INTO UNION FROM OPPOSITE DIRECTIONS.

The three first experiments I shall mention to you, were made by Mr. Atwood, of Cambridge, and are described by him in the Analysis of a course of Lectures, which he read at Cambridge.

He slightly charged the surfaces of an electric insulated plate, and discharged it through an *interrupted* circuit, (formed of needles placed in a groove of wax, the distance between each needle was very small;) the *two powers* were visible, on the discharge illuminating the points of the interrupted circuit, *each power extending further* from the surface *contiguous* thereto, in proportion to the strength of the charge; but when this was sufficiently strong to make the *illuminations proceeding from each side* meet, there was an explosion of the whole charge. The length of the interrupted circuit made by Mr. A. was twelve feet.

Mr. A. charged a cylindrical plate of air, under the receiver of an air-pump, and found that the more the air was exhausted from between the surfaces, the more readily and easily *the powers united.*

He

* Read's Summary View of Spontaneous Electricity, *p.* 81 & 82.

He made an exhaufted receiver part of the electric circuit, and on ufing fuch charges as were not fufficient to form an explofion, he found the electric light proceeding in *oppofite directions* from the parts communicating with the vitreous and refinous furfaces.

When a Leyden jar is charged but flightly, if you touch the coating with a finger of one hand, and at the fame time bring a finger of the other to the knob of the jar, you will receive a fmart blow upon the tip of each finger, but the fenfation reaches no higher. Charge the jar a degree higher, and you will feel a ftronger blow, reaching to the wrifts, but no further. When it is charged fomewhat higher, a fevere blow will be received, but which will not reach beyond the elbows. Laftly, when the jar is ftrongly charged, the fhock will be perceived at the wrifts and elbows, but the principal blow is felt at the breaft, as if a blow from each fide met there. This plain and fimple experiment of Mr. *Symmers* obvioufly fuggefts *the exiftence of two currents proceeding in contrary directions*, accords with thofe of Atwood and Volta, * and is in direct contradiction to that affertion of the Franklinians, " that the *fame* quantity of electric matter, which is thrown upon one of the furfaces of glafs in charging, is driven from the other, and that in the difcharge *this accumulated quantity* is reftored to the deficient furface."

When a jar is charged very high, the *electricities* will often, in their endeavours to unite, force a hole through the jar, and pufh out the coating on both fides, fometimes melting it; the burr of tinfoil protruded from the middle of the glafs ftrongly indicates, that the *two electricities meet* at the

* See my Effays on Electricity.

the middle of the glaſs;* there alſo the greateſt effort is exerted.

Mr. Read ſays, that when the charge for melting of fine wire is of a proper intenſity to melt it into fine globules, he has obſerved the wire to be of a paler red heat in the *middle*, than at the *extremities*, and the melting to begin at the *middle*; leaving a portion unmelted at each end. At other times (though leſs frequent) the wire was obſerved to be of a more glowing heat in two parts, and theſe were generally near the middle. Theſe effects clearly ſhew, that the vitreous and reſinous electricities of the charged jar, met in great force near the *middle* of the wire, which is directly contrary to the leading notions of Franklin's theory.

The remarkable tendency of the divided fluids to unite, is often perceived in a *full* charged Leyden bottle, at the upper edge of the outſide coating, and at the edge of the cork on the neck of the bottle; rays of light darting from *each*, and ſoliciting, as it were, an union, and ſometimes forming an actual circuit.

The same Principles confirmed by the Appearances of the Electric Spark.

The electric ſpark appears of different colours according to it's denſity; when it is rare, it appears of a blueiſh colour; when more denſe, it is purple; when highly condenſed, it is clear and white, like the light of the ſun.

The middle part of an electric ſpark often appears diluted, and of a red or violet colour, while the ends are vivid and white; this appearance cannot be accounted for by the theory of a *ſingle fluid moving in one direction*, but is a proof of *two*

* Read on Spontaneous Electricity, &c. p. 44.

currents moving in *oppoſite* directions; the electric ſigns growing weaker where the two powers unite. Mr. Read * has well, and I believe firſt obſerved, that the place of re-union is much leſs luminous, and in ſome caſes quite dark; and that this is the natural effect of the union of the two electricities; at that point the diſtinctions of *vitreous* and *reſinous* ceaſe, and there the electric light vaniſhes. Theſe appearances are beſt obſerved, by viewing in the dark a ſtrong electric ſpark paſſing between two bodies, electrified with contrary electricities.

Though the appearances of the electric light on a point and ball, as well as of the electric ſpark, are ſubject to many variations, yet are there certain ſigns generally peculiar to *each kind of electricity*. For inſtance, if the reſinous part of a ſpark be ſmall, or what has been uſually termed the luminous globule, then the middle part is generally of a purpliſh colour. When ramified rays iſſue from the vitreous part, then the reſinous is more extended, ſtretching out towards the vitreous. When the vitreous and reſinous electricities ſtrike into each other in denſe light, in various parts of the intermediate ſpace, then their exact place of union is generally obſervable by a *dark ſpot*. Mr. Read, with propriety, conſiders the *loſs of light* in any part of an electric ſpark, whether total or partial, as the immediate effect, and conſtant ſigns of the *re-union* of the two electricities.

Mr. Read obſerves, that whether the reſinous light aſſumes the figure of an *oblong flame*, or of a *luminous globule*, in either caſe the vitreous light is ſeen to approach, and unite with it in all poſſible directions. The effect of a vitreous ſurface appears to extend farther than that of a reſinous ſurface.

THE

* Read's Summary View of Spontaneous Electricity, p. 47, 48, & 49.

The opposite Directions of the two Electricities, proved by the Appearances of the Electric Light in Vacuo.

Though I have already pointed out to you ſome experiments in vacuo, that illuſtrate this point, yet thoſe of Mr. Read's are ſo deciſive, that not to mention them, would be to deprive you of eſſential information on this ſubject.

For theſe experiments, Mr. Read uſed a glaſs tube, 3 feet 7 inches long, furniſhed at each end with braſs caps, one of the caps fitted to the plate of the air-pump; from each cap a braſs wire, on which was a braſs ball, projected within the tube; when this tube is ſufficiently rarified, the charge of a Leyden phial will readily paſs through the rarified air.

In making theſe experiments, you muſt only ſlightly charge your Leyden jar; for if the charge is ſtrong enough to force the whole contents ſwiftly through the rarified air, the motion of the fluid is too rapid, and the light too reſplendent to permit an exact obſervation of it's appearance.

On making the diſcharge in the dark, you will perceive, the moment the circuit is formed for that purpoſe, a light within the tube, but chiefly at *each end.* Theſe lights are of the contrary kinds of electricity, and accord with the ſide of the bottle to which they are connected. You may ſometimes perceive the two lights to have a manifeſt tendency to *meet* near the middle of the reſiſting medium. Mr. Read has obſerved the light within the tube to be conſiderably diminiſhed in ſplendor, where the two powers unite, and ſo it ought to be, for when the two electricities unite, and regain their natural ſtate, they loſe their light, *for it is only in a divided ſtate, that the electrical matter is luminous;* the ſame appearances are pro-

duced in the tube by the ſimple ſpark, that is, the *contrary electricities* are obſerved at each end.*

But this is ſtill further confirmed by a new obſervation, and deciſive experiment of Mr. Read's. He ſuſpended his exhauſted tube in an horizontal direction, by ſilk lines from the ceiling; † one end was placed ſo as to receive an electric ſpark from the conductor of his machine, at half an inch from the other end; there was a metalic communication with the earth.

On turning the machine, the tube is filled with electric light, and continues ſo long as the action of the machine is continued. Mr. Read firſt obſerved, that the inſtant the ſupply ceaſes, *the light divides near the middle of the tube, and flies back to the ends;* fully evincing the truth of Mr. Eeles's theory, by ſhewing *that the light within the tube is not all of one kind of electricity;* the tube includes *both* electricities in *one* appearance of light; the moment the action of the machine is diſcontinued, the *afflux* and *efflux* ceaſes, and each electricity returns to it's own place, where the ſeparation firſt commenced.

To aſcertain beyond diſpute, that the light within this kind of exhauſted tube conſiſted of vitreous and reſinous light, he made the following experiment. The glaſs tube was ſuſpended as before, and two Leyden phials in an horizontal poſition, but lying on glaſs ſtands, were placed one at each end of the tube, with their metallic knobs nearly in contact with the metallic caps of the glaſs tube. In this diſpoſition of the apparatus, the *coating* of one bottle is to receive a ſpark from the prime conductor, and the *coating* of the other a ſpark

* Read, p. 51. 52, 53.

† It is more convenient to inſulate the glaſs tube, or luminous conductor by glaſs pillars, as fig. 13, pl. 1.

a ſpark from the metallic communication with the earth.

On turning the cylinder, ſparks were perceived to paſs in the four intervals of air, and at the ſame time a luminous appearance within the glaſs tube. On removing the bottles, and examining their charges, they were found to correſpond with the lights within the tube, to which they were oppoſed. One bottle was vitreouſly, the other reſinouſly electrified.*

Theſe experiments clearly prove, that there is at the ſame time *one power* acting from within, towards the outſide of a charged Leyden phial, and another power acting from the outſide towards the inſide of the phial; and thus concur with others in ſhewing, that electricity conſiſts of two diſtinct poſitive powers acting in contrary directions, and towards each other.

Here is a coated flaſk from which the air has been exhauſted, that you will find, on trial, to illuſtrate pleaſingly the theory of electricity, *fig.* 14, *pl.* 1.

From the experiments on the theory of the Leyden bottle, I ſhall now proceed to ſome entertaining ones with the ſame inſtrument. No electrical experiments anſwer ſo well the joint purpoſes of pleaſure and ſurpriſe, as thoſe that are made with the Leyden phial. And philoſophers are ſo far from laughing at the aſtoniſhment of the ignorant at theſe experiments, that they cannot help viewing them with equal, if not greater aſtoniſhment themſelves. There are indeed, as Dr. Prieſtley has obſerved, many electricians ſtill living, who can well remember the times when, with reſpect to

* Mr. Eeles, from his theory, pointed out in 1758, the mode of making this experiment, and foretold what would be the reſult. This is only one among many inſtances, where in reaſoning *a priori*, he has pointed out reſults, that the Franklinians of the day denied.

these things, they themselves would have ranked among the same ignorant and staring vulgar.

What would the ancient philosophers have said, what would Newton himself have said, to see the present race of electricians imitating, in miniature, all the known effects of lightning; nay, essaying to disarm the thunder of it's power of doing mischief, and without any apprehension of danger to themselves, drawing lightning from the clouds into a private room, and amusing themselves at their leisure, by performing with it all the experiments that are exhibited by electrical machines?

One cannot indeed consider the present improved state of philosophy, without indulging, with the Rev. Mr. Jones, a wish to exhibit to the wise men and heroes of ancient times, some of those wonderful improvements which are now so familiar to us, but were totally unknown to them.

I would give, says he, to Aristotle, the electrical shock: I would carry Alexander to see the experiments upon Woolwich Warren, and exhibit to him all the evolutions and firings of a modern battalion: I would shew to Julius Cæsar, the invader of Britain, an English man of war; to Archimedes a steam engine, and a reflecting telescope.*

Entertaining electrical experiments are not without their use, for they even give philosophic minds an opportunity of viewing things under different points of view, and often arrest their attention on objects which had before escaped their notice.

To strike a hole through a card. Having charged your jar, hold a card with one hand close to the coating of the jar near the bottom, then apply one knob of the discharging rod to the card, and the other

* Jones's Physiological Disquisitions.

other to the ball of the bottle, and the discharge will pass through the card, and will make a hole through it with a bur on each side, of which I shall take more notice hereafter; it will have a strong sulphureous smell.

If the experiment be made with two cards instead of one, (the cards must be placed but at a very small distance from each other) each of the cards, after the explosion, will be found pierced with one or more holes, and each hole will have burs on both surfaces of the card.

To stain paper, you must lay a chain upon a sheet of white paper, and pass a shock through it; the paper will be found to be stained with a blackish tinge at every juncture of the links. If you make this experiment in the dark, a spark with a kind of radiation will be seen at each juncture; and the chain will appear illuminated like a line of fire; an *iron* chain answers best the purpose.

You may also, by the discharge, *stain glass with gold leaf*; for this end, take two slips of common window glass, each about an inch broad, and 3 or 4 inches long; then take a narrow slip of gold or silver leaf, and put it between the glasses lengthwise, letting the ends of the leaf hang half an inch without the glasses at each end; place the glasses in the small wooden press, and fix them there by a gentle pressure, and then lay them down on the table, so that one end of the metal leaf may be in contact with the coating at the bottom of the jar; and when the jar is charged, put one end of the discharged rod upon that part of the leaf that lies without the glass, which is farther from the jar, and apply the other end of the discharger to the top of the jar, and the fluid will pass through the metal leaf; and when the glasses are taken asunder, you will find, that the leaf has been actually

melted by the electric lightning, and driven into the very ſubſtance of the glaſs.

A pane of glaſs, coated on each ſide, the coating being every where about two inches from the edge, with a picture paſted on the upper ſide, and put into a frame, is called the *magic picture*; one line of tinfoil that goes from the coating of the under ſide, is made to communicate with the bottom of the frame; the back edge of the bottom rail and the frame is covered with tinfoil. Set the face of the picture againſt the ball of the conductor, and turn the machine. Then take it away, and holding it in an horizontal poſition by the top of the frame, lay a ſmall piece of money upon the head. You may then deſire any perſon to take hold of the lower rail of the frame with one hand, and to take off the piece of money with the other; in attempting to do this, he will fail of his deſign, for the moment he touches the money he will receive a ſtrong ſhock. You muſt continue to hold the frame all the while, and will have nothing to fear, becauſe none of the electric virtue, with which the picture is charged, can come to you, as you are not in the circuit.

This bottlcalled is the *ſpotted bottle*, becauſe it is only coated with ſmall pieces of tinfoil, placed at a little diſtance from each other; charge this bottle in the uſual manner, and you will ſee ſtrong ſparks of electricity fly from one ſpot of tinfoil to the other, making the paſſage of the fluid on the outſide very viſible. Diſcharge this bottle, by bringing a pointed wire gradually near the knob, and the uncoated part of the glaſs between the ſpots will be pleaſingly illuminated, and the noiſe will reſemble that of ſmall fired crackers. If the jar is diſcharged ſuddenly, the outſide ſurface appears illuminated. To produce theſe appearances, the glaſs muſt be very dry.

Hold a phial in the hand which has no coating

ing on the outſide, and preſent it's knob towards an electrified conductor; the fire, while it is charging, will paſs from the outſide to the hand, in a pleaſing manner; on the diſcharge, beautiful ramifications will be ſeen upon the uncoated part of the jar.

By ſetting fire to ſome tow in a tin houſe, you have a repreſentation of that awful appearance, *a houſe in flames*. To make this experiment ſucceed, take a piece of ſoft tow, dry it well, and then rub, or fill it pretty well with roſin, and place it between the balls in the inſide of the houſe; the balls ſhould not be far aſunder, nor the charge too high; connect the hook at the bottom of the houſe, with the bottom of the jar; let the top of the jar be connected with the conductor, and when it is charged, put one ball of the jointed diſcharger on the conductor, and bring the other down upon the ball above the houſe; the exploſion will ſet the tow on fire, whoſe flames will paſs through the windows, and make the houſe appear like one on fire.

You may pleaſingly illuſtrate the nature of the Leyden phial, by ſuſpending two ſets of bells therefrom; one ſet connected with the inſide, the other with the outſide; ſee *fig.* 16, *pl.* 1. Hook up the chain from the bells communicating with the inſide, that they may have no connection with the table; charge the bottle in the uſual manner; during the charge, the ſet ſuſpended from the outſide will continue to ring. After the bottle is charged, unhook the wire of the bells ſuſpended from the inſide. Touch now the wire A, and the bells will ceaſe ringing, but the other ſet will begin to act; take the finger from A, and apply it to B, and the bells at B will be quiet, while thoſe at A will be ſet in motion, and ſo on alternately, till the bottle is diſcharged.

EXPERI-

EXPERIMENTS WITH THE ELECTRICAL BATTERY.

The moſt formidable part of the electrical apparatus is the *electrical battery*, that is, a number of jars connected together in a box; the bottom of the box is covered with tin-foil; from theſe a hook projects on the outſide of the box, by which any ſubſtance may be connected with the outſide of the jars; their inſides are all connected by wires.

With a battery[*] you may perform a great number of very ſurpriſing and intereſting experiments; and though, if very large, it be a formidable appendage to an electrical machine, and ought always to be uſed with caution, yet it cannot be ſaid, that the apparatus of an electrician is complete without it; it's effects in rending various bodies, in firing gunpowder, in melting wires, and in imitating all the effects of lightning, never fail to be viewed with aſtoniſhment.

There is ſome caution neceſſary, in the uſe and management of a battery, and you ſhould be careful never to make part of the circuit, and to prevent thoſe that are ſeeing the experiments touching the battery, or approaching too near to any part of the apparatus; the quadrant electrometer ſhould be always uſed with it; it is beſt to place it upon the ball, which unites the internal wires, but it ſhould always be elevated two or three feet above the ball. A battery cannot be charged ſo high in proportion, as a ſingle jar; the quadrant electrometer, therefore, never riſes ſo high as 90 degrees, ſeldom higher than to 60 or 70 degrees, more or leſs, in proportion to the ſize of the battery, and the force of the machine. I muſt obſerve to you here, that if one jar in your battery be broke,

you

you muſt remove the broken jar, before the reſt can be charged.

Mr. Atwood made, with his battery, a very curious experiment *on the perforation of paper by the electric fluid;* combined with thoſe that I ſhall afterwards relate to you, you will find it prove, with great clearneſs, the exiſtence and action of the two electric powers.

He ſuſpended a quire of paper by a line, in the manner of a pendulum, from a convenient altitude, ſo that it's plane might be vertical. The largeſt charge from a battery was paſſed through it, while quieſcent in an horizontal direction perpendicular to the plane, the rods of communication not touching the paper; the phenomena were, *firſt*, the aperture mentioned in the leaves, being protruded both ways from the middle:* *ſecond*, not the ſmalleſt motion was communicated to the paper from the force of the diſcharge.

A quire of the thickeſt and ſtrongeſt paper was made uſe of for this experiment, the height from which it was ſuſpended ſixteen feet. It is an extraordinary appearance on the hypotheſis of a ſingle electric fluid, that a force ſufficient to penetrate a ſolid ſubſtance of great tenacity and coheſive force, ſhould not communicate the ſmalleſt motion to the paper, when a breath of air would cauſe ſome ſenſible vibration in it. But the other phenomenon, i.e. the oppoſite direction in which the leaves are protruded, tends very much to *ſtrengthen the opinion of two oppoſite currents;* indeed when the two facts are taken together, it is ſcarcely poſſible to reconcile the hypotheſis of a ſingle power with matter of fact.

Mr.

* The bur of the paper pointed one way on one ſide, and the oppoſite way on the other ſide, as if the hole had been made in the quire, by drawing two threads through it, in a contrary direction.

Mr. Symmer placed in the middle of a paper book, of the thickneſs of a quire, a ſlip of tin-foil; in another of the ſame thickneſs he put two ſlips of tin-foil, including the two middle leaves between them; upon paſſing the electric ſtroke through them, he found the following effects. In the firſt, the leaves on the ſide of the foil were pierced, while the foil itſelf remained unpierced; but at the ſame time he could perceive, that an impreſſion had been made on each of it's ſurfaces, at a ſmall diſtance from each other; ſuch impreſſions were ſtill more viſible on the paper, and might be traced as pointing different ways. In the ſecond, all the leaves of the book were pierced, excepting the two holes that were between the ſlips of foil, and in theſe two, inſtead of holes, the two impreſſions *in contrary directions* were viſible.

When a quire of paper, without any thing between the leaves, is pierced by the electrical ſtroke, the two powers keep in the ſame track, and make but one hole in their paſſage through the paper; not but that the power from above, or that from below, ſometimes darts into the paper at two or more different points, making ſo many holes; but theſe generally unite before they go through the paper. They ſeem to paſs each other about the middle of the quire, for there the edges are moſt *viſibly bent different ways;* whereas, on the leaves near the outſide, the holes very often carry more the appearance of a power iſſuing out, than of one darting into the paper.

When any thin metallic ſubſtance, ſuch as gilt leaf, or tin-foil, is put between the leaves of the quire, and the whole is ſtruck; the counteracting powers diviate from the direct track, and make their way in different lines to the metallic body, and ſtrike it in two different points diſtant from one another,

about

about ¼ of an inch, more or leſs; the diſtance appearing to be generally leſs when the power is greateſt; and whether they pierce or only make impreſſions upon it, they *leave evident marks of motion from two different parts, and in two contrary directions.*

When two ſlips of tin-foil are put into the middle of the quire, including two or more leaves between them, if the electricity be but weak, the counteracting powers only ſtrike againſt the ſlips, but leave an impreſſion; if the ſhock be ſtronger, one of the ſlips is pierced, but ſeldom both; and it appeared in general to Mr. Symmer, that the power which iſſued from the outſide, acts with greater force, than that which proceeded from within.

To break thick pieces of glaſs. Place a thick piece of glaſs on the ivory plate of the univerſal diſcharger, *fig.* 15, *pl.*1, and a thick piece of ivory on the glaſs, on which a weight from one to ſeven pounds is to be placed; take off the balls a, b, bring the points of the wires againſt the edge of the glaſs, and paſs the diſcharge through the wires, by connecting one of the wires with the hook of the battery, and forming a communication, when the battery is charged, from the other wire to the ball. By this operation the glaſs will be broken, and ſome part of it ſhivered to an impalpable powder. When the piece of glaſs is ſtrong enough to reſiſt the ſhock, the glaſs is often marked by the exploſion with the moſt lively and beautiful colours.

Place a piece of very dry white wood between the balls of the univerſal diſcharger, the fibres of the wood to be in the ſame direction with the wires, paſs the ſhock through them, and the wood will be torn to pieces; or run the points into the wood, and then paſs the ſhock through them.

To melt wires by the electrical fluid, you ought

ought to have a battery containing at leaſt 30 ſquare feet of coated ſurface; you may then connect the outſide coating with a wire of about $\frac{1}{50}$th of an inch in diameter, and from 12 to 24 inches in length; faſten the other end of the wire to one of the balls of the diſcharging rod; on making the diſcharge, the wire will become red hot, then melt and fall upon the floor or table in glowing globules. Sometimes the ſparks are thrown to a conſiderable diſtance, if the force of the battery be very great, they will be entirely diſperſed by the exploſion.*

* For a further variety of experiments, ſee my Eſſay on Electricity.

LECTURE

LECTURE XLVIII.

On Lightning, and the Usefulness of Metallic Conductors to defend Buildings from it's Effects.

NOTHING can be more natural than to paſs from the electrical battery to lightning itſelf, for the former ſeems to be more than an imitation; it is nature inveſted with her own attire. The light and ſound accompanying theſe phenomena, when exhibited on the great ſcale of nature, are indeed ſo awfully ſublime, that we can ſcarce with propriety reflect on the weakneſs of thoſe, who, in ages leſs informed, ſuppoſed it to be the immediate miniſter of vengeance from an angry Deity. They are now more rationally conſidered, as the natural means of reſtoring a neceſſary equilibrium; the rough diſcords of nature productive of general harmony.

The phenomena of lightning are always ſurpriſing, and ſometimes terrible; there is no appearance in which there is more diverſity, no two flaſhes being obſerved exactly ſimilar to each other.

On a ſummer's evening, it may often be perceived to play among the clouds; this kind is quite inoffenſive, and is not accompanied with thunder.

When the lightning is accompanied with thunder, it is well defined, and has generally a zigzag form; ſometimes it only makes one angle like the

the letter V, sometimes it appears like the arch of a circle. But the most formidable and destructive form which lightning is ever known to assume, is that of *balls of fire*. The motion of these is very often easily perceptible to the eye, but wherever they fall, much mischief is the result of their explosion. The next to this, in it's destructive effects, is the zig-zag kind; for that species, whose flashes are indistinct, and whose form cannot be easily observed, is seldom known to do much hurt. You may consider the colour of lightning as an indication of it's power to do mischief, the palest and brightest flashes being most destructive.

There seems to be a kind of *omnipresent* property in the ziz-zag kind of lightning when near. If two persons are standing in a room, looking different ways, and a loud clap of thunder happens, accompanied with the ziz-zag lightning, they will both distinctly see the flash, not only by that indistinct kind of illumination of the atmosphere, which is occasioned by fire of any kind, but the very form of the lightning itself, and every angle it makes in it's course will be as distinctly perceptible, as though they had looked directly at the cloud from whence it proceeded. If a person was at that time to be looking on a book, or other object which he held in his hand, he would distinctly see the form of the lightning between him and the object. This property seems peculiar to lightning.

The effects of lightning are generally confined within a small space; and are seldom similar to those which accompany explosions of gunpowder, or of inflammable air in mines. Instances of this kind, however, have occurred; the following is one of the most remarkable of which we have any distinct account: "August 2, 1763, about six in the evening, there arose at Anderlight, about a league

league from Bruſſels, a conflict of ſeveral winds borne upon a thick fog. This conflict laſted four or five minutes, and was attended with a frightful hiſſing noiſe, which could be compared to nothing but the yellings of an infinite number of wild beaſts. The clould then opening, diſcovered a kind of very bright lightning, and in an inſtant the roofs of one ſide of the houſes were carried off and diſperſed at a diſtance; above 1000 large trees were broke off, ſome *near the ground*, others *near the top*, ſome torn up by *the roots*; and many both of the branches and tops carried to the diſtance of 60, 100, or 120 paces; whole coppices were laid on one ſide, as corn is by ordinary winds. The glaſs of the windows which were moſt expoſed was ſhivered to pieces. A tent in a gentleman's garden was carried to the diſtance of 4000 paces; and a branch torn from a large tree, ſtruck a girl in the forehead as ſhe was coming into town, at the diſtance of 40 paces from the trunk of the tree, and killed her on the ſpot."

Thunder-ſtorms will ſometimes produce moſt violent whirlwinds, ſuch as are by ſome philoſophers attributed to electricity; nay, even occaſion an agitation of the waters of the ocean itſelf; and all this too after the thunder and lightning has ceaſed. Of this we have the following inſtances. "Great Malvern, October 16, 1761. On Wedneſday laſt we had the moſt violent thunder ever known in the memory of man. At a quarter paſt four in the afternoon, they were ſurpriſed with a moſt ſhocking and diſmal noiſe; 100 forges all at work at once, could ſcarce equal it. Upon the ſide of the hill about 400 yards to the ſouth-weſt, there appeared a prodigious ſmoke, attended with the ſame violent noiſe, as if a volcano had burſt out of the hill; it ſoon deſcended, and paſſed on within about 100 yards of the ſouth

end of the houfe; it feemed to rife again in the meadow juft below it, and continued it's progrefs to the eaft, rifing in the fame manner for four different times, attended with the fame difmal noife as at firft; the air being filled with a naufeous and fulphureous fmell; it gradually decreafed till it was quite extinguifhed in a turnip field, about a quarter of a mile below the houfe; the turnip leaves, with leaves of trees, dirt, fticks, &c. filled the air, and flew higher than any of thefe hills. The thunder ceafed before this happened, and the air foon afterwards became calm and ferene."

Lightning is in the hands of nature, what electricity is in our's; the wonders we now exhibit at pleafure are little imitations of thofe great effects which frighten and alarm us, they feem to depend on the fame mechanifm; the fame properties, the zig-zag fparks, their fimilar action on conducting fubftances, the power of rending, inflaming, and difperfing in every direction the fubftances on which it acts with power, the giving polarity to ferruginous matter, &c. all concur to fhew their identity. But independent of thefe fimilarities, the thing is proved by the plaineft and cleareft evidence; when the atmofphere is charged with thunder clouds, we can by an *electrical* kite draw from it the matter of lightning, and with this matter perform every known electrical experiment.

You have feen, that the electric powers never become fenfible to us, except when they are feparated, and then chiefly in their paffage from one body to another in oppofite directions; and *that an equal quantity of a different power muft be conducted from the earth to the cloud to produce lightning.* There muft be the fame reciprocal exchange of powers to occafion lightning from one cloud to another.

When two clouds, which are highly electrified with the different powers, come near together, they approach

approach with an increaſing force till they flaſh in exchanging powers. But as clouds are formed of diſtinct particles, and every particle has it's ſhare of *both the electric powers*, according to the equality or inequality of quantity of each power in each particle, it is more or leſs electrified; and on the various combinations of theſe powers, will ariſe the mode in which the clouds approach each other, and in which they exchange their different powers.

When the electrified particles are made ſo to approach each other, that their atmoſpheres are preſſed off together to a great diſtance from the cloud, they then act nearly the ſame as if the cloud was one continuous body; but after the flaſh, thoſe particles which have exchanged powers, and in which the two electricities are united, being no longer buoyed up by theſe agents, fall down in rain, hail, &c.

That theſe atmoſpheres are extended to a great diſtance from the cloud, appears from all experiments made both here and abroad; for in them it is plain, that an atmoſphere *goes up from the earth* of the power which is contrary to that of the cloud, which would not take place if the atmoſphere of the cloud did not reach the earth.

When one of theſe highly electrified clouds approaches ſo *near to the earth as to exchange powers with it*, then is the damage done to thoſe things through which the exchange is made, which are generally thoſe bodies that riſe neareſt the cloud.

Many are the obſervations which ſhew, that the atmoſphere of the clouds are condenſed at the time of their joining by a flaſh, and that the contrary electricity is then as it were drawn up from the earth. Thus in Mr. Ludolf's account, Phil. Tranſ. vol. 47, at every clap of thunder the electricity ſeemed extinct, and did not return till after the ſpace of about 30 ſeconds; the threads

 which

which by their divergence indicated the electricity, approached each other ſuddenly, as if they had been puſhed together with force. The Abbe Nollet, and many others have obſerved ſimilar appearances. In an obſervation of Abbe Nollet, the clap of thunder put a ſtop for ſome time to the force of the electricity; all this may be eaſily illuſtrated by our electrical apparatus. Bring two cork balls ſuſpended by linen threads from the end of a wire, within the atmoſphere of an electrified conductor, and they will be electrified with a power contrary to that which electrifies the conductor, receding from each other, but flying towards the conductor; take a ſpark from the conductor, and they immediately collapſe, the electricity drawn into them from your body returning thereto.

It often happens, as before obſerved, that clouds electrified with the contrary powers are driven together, and the particles coming into contact, the powers are exchanged without that violent flaſh which uſually accompanies a thunder ſtorm. In this caſe, the particles generally deſcend in heavy ſhowers of rain; but the exchange of powers is moſt complete in the middle of the united clouds, and the heavieſt part of the ſhower is generally from the middle of the cloud.

In confirmation of this, I ſhall only mention one obſervation, though many might be produced; it was made by Mr. Eeles in October, 1760; the clouds were very diſtinct, and the ſhowers heavy. In three different clouds he found the ſhowers from the beginning electrified with the vitreous power; the ſhowers from the middle of each cloud ſhewed no ſign of electricity, and the end of each cloud was reſinouſly electrified, the wind N.W. There was no appearance of electricity in the middle of the ſhowers, becauſe the electric powers are there united

united to each other in every drop; their atmospheres and actions were therefore insensible.

Rain, hail, and snow, often exhibit signs of being electrified, for the clouds are seldom so equally electrified with the different powers of electricity, as upon meeting to render them equal in each descending drop. In large flakes of snow, the electricity is often very evident; for when they come near a non-electric body, they are driven towards, and cling about it like an electrified feather.

It is not easy to form any idea of what some writers mean, by a negative cloud, or a negative stroke. Is it a mere inanity which knocks down steeples, rends trees, tears up the earth, and kills men and cattle, &c.? Can that which is not, act?

You saw by an experiment I lately exhibited to you, that if two electric plates (or two jars) be charged, and a communication be made from the vitreous side of one, to the resinous side of the other; no discharge will follow, unless a communication is formed between the other two surfaces at the same time.

The natural electricity in the atmosphere is frequently discharged in this manner: two clouds being electrified with opposite powers, the surfaces of the earth immediately under them are likewise electrified with powers contrary to those in the clouds above them; and the moisture of the earth forming a communication between the two contiguous charged surfaces, whenever the two clouds meet, there will follow a discharge, both of the clouds and surfaces on the earth opposed to them. If the earth should be dry, and consequently afford a resistance to the union of the two electricities accumulated on or under it's surface, there will follow an explosion in the earth as well as in the atmosphere, which will produce concus-

ſions and other phenomena which have frequently been obſerved to happen in dry ſeaſons, particularly in thoſe climates which are the moſt liable to ſtorms of thunder and lightning.

The various caſes of lightning are too numerous to be here conſidered, and too imperfectly known to be accurately explained. What I have ſaid, will, I hope, give ſome general notions of the method in which it operates, and lead you to a further inveſtigation of the ſubject. You may from thence alſo readily account for it's ſeemingly capricious nature; ſometimes it will ſtrike trees, high houſes, &c. without touching cottages, men, or animals in the neighbourhood; while in other inſtances, low houſes and cattle have been ſtruck, while high trees, ſteeples, &c. near them have eſcaped.

All this is very eaſily accounted for, upon Mr. Eeles's theory of a double current, and the efforts in nature to reſtore the electrical fluid to a latent ſtate, whenever by any means the powers thereof have been ſeparated. Thus in great thunder ſtorms, there is a portion of the earth under the cloud which is electrified thereby, with the contrary electricity; thoſe objects therefore, which form the moſt perfect conductors between the clouds and that portion of the earth, will moſt probably be ſtruck, as being the readieſt way by which the two oppoſite powers can unite, and reſtore the electrical equilibrium both in the cloud and the earth, one part of the flaſh *aſcending* from the earth, the other *deſcending* from the cloud.

Let us ſuppoſe a cloud vitreouſly electrified, to be formed over a certain parts of the earth's ſurface; the electric power of the cloud firſt ſeparates that of the atmoſphere, and while it is thus operating, the atmoſphere is reſinouſly electrified; in

in a little time the air becomes vitreoufly electrified, and then both it and the cloud act as one body. The furface of the earth then begins to be electrified, and the powers therein to be feparated, and a continual effort is made by the contrary electricities to unite between the earth and the cloud. If thofe caufes which firft produced the electricity ftill act, the power becomes inconceivably great, and the flafhes in uniting will tear every thing to pieces that refift their paffage.

Mr. Read juftly obferves, that a portion of the earth may be highly electrified, and yet we may be infenfible thereof, becaufe we are involved therein; for where all things are equally involved in an electrical atmofphere, there can be no vifible figns of the prefence of the electric matter. Thus if two or more perfons be electrified, while ftanding on the *fame infulation*, they fhew no figns to each other of being electrified.* Whatever be a perfon's fituation, whether in the houfe or open field, he is liable to be involved in an electric charge, whether it be ftationary, or moving with the clouds. Mr. Read found himfelf fo involved once in Hyde Park; the atmofphere had a menacing appearance with a heavy black cloud at no great diftance; on taking his pocket electrometer out of it's cafe, and holding it in his hand, it inftantly diverged near one inch. It is not probable, that the reftoration of the equilibrium, or *returning ftroke*, as it is often called, will hurt any one, unlefs they are in the direct path of the flafh.

I have already obferved, that it is probable that the operations of the electrical matter are moft univerfal and important in it's latent and united ftate; and that whenever by feparation it becomes vifible, there is then a general ftrefs

 throughout

* Read, p. 61. Ibid. p. 68.

throughout the greater part of our syſtem, to reſtore the equilibrium; and that this ſtreſs is greater in proportion to the quantity ſeparated; that this ſeparation in many inſtances is *ſpontaneous*; and that as this fluid is univerſally diſſeminated, there is no occaſion to conſider the appearance of electricity in vapour, &c. as the means whereby this fluid is conveyed to the clouds.

From M. de Luc's obſervations, it would hence appear, that lightning often ariſes from ſudden production of a great quantity of the electrical fluid, that which is then manifeſted, not being apparent as electricity, but juſt before we perceive it's effects. This is further confirmed by his obſervations when on mountains, where he had often opportunities of viewing theſe phenomena. Thus in a ſtorm on the *Buet*, (one of the Alps) while the air was perfectly tranſparent and dry, (the laſt circumſtance being determined by the hygrometer) clouds began to form in different parts; theſe, when thickened and united, embraced the ſummit of the *Buet*, and ſupported themſelves againſt *Mount Blanc*, and the ſummits of the neighbouring mountains. Mr. de Luc and his companions were overwhelmed with rain; there was alſo a vaſt deal of lightning, which was often violent, and laſted for a conſiderable time. Mr. de Sauſſure has alſo given inſtances where the clouds formed a conducting communication with the ground, and yet the lightning continued without interruption.

From theſe phenomena, *air* perfectly *tranſparent* and *dry*, containing neither the vapours of which the cloud is formed, nor the electric fluid, but only the ingredients proper to give them birth; he infers, that by ſome unknown cauſe, clouds of a certain kind are formed ſpontaneouſly, and dur-

ing the progreſs of their formation, the electricity is produced in great abundance, exploding every time it is thus formed; and that before this, the electric fluid no more exiſted in that ſtate, than the aerial fluids, which are diſengaged from gunpowder, exiſted as ſuch before the gunpowder was exploded. I need ſcarce obſerve to you, how much Mr. Eeles's theory is confirmed by this account of Mr. de Luc.

You may gain ſome idea of the prodigious quantity of the electric fluid, that is ſometimes manifeſted, and paſſing between the clouds and the earth, by an inſtance or two with which we are furniſhed by Mr. de Luc. Thus a cloud was obſerved at the top of the mountains of Turin: it was formed of a maſs, whoſe obſcurity rendered it terrific, producing in thoſe places, over which it was ſituated, *night* at noon day; this maſs was ploughed as it were by lightning, which was ſoon after followed by a grumbling kind of thunder; there fell ſo prodigious a quantity of water and ice from this cloud, that the country was ravaged by the torrents, the hedges were beat down, and the ditches half filled with hail. Erfurt, a ſmall city in Germany, was ſtruck in one night in forty-two different places; ſeven perſons were killed, three houſes were ſet on fire, but quenched by the rain, which came down in torrents. Now where ſhall we find, on the vapour theory, known *humidity* in any ſtrata of tranſparent air, ſufficient to explain the formation of ſuch clouds, and the torrents of *rain* which was diſcharged from them?

Of Conducting Rods.

We are now prepared to conſider the advantage of conducting rods. You know that the electrical fluid is always impelled to thoſe places where an

an exchange of powers can be moſt eaſily made, or where the union of the two powers is leaſt reſiſted. If, then, there happens in any of the preceding inſtances to be a houſe furniſhed with a conducting rod, directly between that part of the cloud, and that part of the earth, where there is the greateſt effort for reſtoring the equilibrium, the conductor will be ſtruck, and will probably prevent the building from receiving any injury. If there be no conductor, the lightning will for the foregoing reaſons paſs at the ſame place, but the building will probably be damaged, becauſe the materials reſiſt the paſſage of the electrical powers.

OF POINTED AND KNOBBED CONDUCTORS.

A great diſpute has been carried on among electricians concerning the termination of conducting rods, for preſerving buildings from lightning; ſome warmly contending that they ſhould be terminated by *knobs or balls*; others as ſtrenuouſly contending, that they ſhould be *pointed.*

Ever ſince the identity of electricity and lightning has been proved, conductors of ſome kind have been generally allowed to be neceſſary for the ſafety of buildings in thunder ſtorms, as they afford a ready paſſage for the union of the contrary electricities. Electricians ſeem to have forgot that neither lightning nor electricity ever ſtrike a body, merely for the ſake of the body, but becauſe that body is a means of reſtoring the diſturbed equilibrium.

When a quantity of electricity is excited by means of an electric machine, a body communicating with the earth, will receive a ſtrong ſpark from the prime conductor; it receives this ſpark, not becauſe it is capable of containing all the electricity

of the cylinder and conductor, but becauſe the natural ſituation of the fluid being diſturbed by the motion of the machine, the natural powers make an effort to reſtore the equilibrium. No ſooner, then, is a conducting body, communicating with the earth, preſented to the prime conductor, than the whole effort of the electricity is directed againſt that body; not merely becauſe it is a conductor, but becauſe it affords a place, by which the natural powers can more readily unite, and which they would do by other means, though that body were not to be preſented. That this is the caſe, we may eaſily ſee, by preſenting the ſame conducting ſubſtance in an inſulated ſtate to the prime conductor of the machine, when we ſhall find only a ſmall ſpark will be produced. In like manner, when lightning ſtrikes a tree, a houſe, or a conducting rod, it is not becauſe theſe objects are high, but becauſe they are ſituated in that place, where, from a variety of cauſes, the impetus of the two powers can be leſſened by uniting with each other.

From hence you will perceive the fallacy of that kind of reaſoning, which is generally employed concerning the uſe of thunder rods.

Becauſe a point preſented to an electrified body in our experiments, draws off the electricity in a ſilent manner, Dr. Franklin and his followers have concluded, that a pointed conductor will do the ſame thing to a thunder cloud, and thus prevent any kind of danger from a ſtroke of lightning.

But for this very reaſon, Mr. Wilſon and his party have determined, that the uſe of pointed conductors is utterly unſafe; they juſtly conſider the Franklinian idea of exhauſting the clouds of their electricity, to be not leſs abſurd, than it would be, to clear away an inundation with a ſhovel, or exhauſt the atmoſphere with an air-pump.

They

T bring many inſtances, where a point will receive a *full* ſtroke, and aſſert that it ſolicits a diſcharge, and that being often unable to conduct the whole electricity of the atmoſphere, it is impoſſible for us to know whether the diſcharge they ſolicit, may not be too great for our conductor to bear, and conſequently all the miſchiefs ariſing from thunder ſtorms may be expected, with this mortifying circumſtance, that this very conductor hath probably ſolicited the fatal ſtroke.

I muſt alſo further obſerve to you, that the Franklinians, granting them all they aſk, ſtill make their pointed conductors of too much conſequence; for it is now well known, that points have no influence at all, unleſs they are immerged in the electrified atmoſphere. If a pointed body does not communicate with the earth, but the communication is interrupted by a ſhort interval, it will receive a full ſpark. It will alſo receive a full ſpark, if it be *ſuddenly* brought ſufficiently near a ſtrongly electrified body; this caſe applies ſtrongly againſt pointed conducting rods for ſhipping. It will alſo receive a full ſpark at a conſiderable diſtance, if ſurrounded with non-conducting ſubſtances. The circumſtances, on which an exploſion depend, are too many to be here enumerated; in general it may be ſaid that with reſpect to a point, it will depend on the *ſuddenneſs of the diſcharge, on the proximity of the cloud, on the velocity in it's motion, on the quantity of electricity contained in it, and on the contrary electricity oppoſed to it.* If a ſmall cloud hangs ſuſpended under a large cloud loaded with electric matter, pointed conductors on a building underneath, will receive the diſcharge by exploſion, in preference to thoſe terminated by balls; the ſmall cloud will form an interruption, which allows only an inſtant of time for the diſcharge. If a ſingle

gle electric cloud is driven with confiderable velocity near to a pointed conductor, the charge may be caufed to explode upon it by the motion of the charged body.

A pointed conductor has not even the power of *attracting* the lightning a few feet out of the direction it would choofe itfelf: of this we have a moft decifive inftance in what happened to the magazine at Purfleet, in Effex. That houfe was furnifhed with a conductor, raifed above the higheft part of the building; neverthelefs, a flafh of lightning ftruck an iron cramp in the corner of the wall of the building, confiderably lower than the top of the conductor, and only forty-fix feet in a floping line diftant from the point.

The conductor, with all it's power of *drawing off* the electric matter, was neither able to prevent the flafh, nor to turn it forty-fix feet out of it's way. The matter of fact is, the lightning was determined to enter the earth at the place where the Board-houfe ftands, or near it; the conductor, fixed on the houfe, offered the eafieft communication, but forty-fix feet of air intervening between the point of the conductor and the place of the explofion, the refiftance was lefs through the blunt cramp of iron, and a few bricks moiftened with the rain to the fide of the metalline conductor, than through the forty-fix feet of air to it's point, for the former was the way in which the lightning actually paffed.

An objection to the ufe of conductors of either kind may be alfo drawn from the accident which happened to the poor houfe at Heckingham, Norfolk, which was ftruck by lightning, though furnifhed with eight pointed conductors, and which, I am well affured from good authority, were *uninterrupted, continuous,* and at the time of

of the ſtroke *perfectly connected* with the common ſtock. Hence it is evident, that the effect of conductors, in general, is too inconſiderable either to leſſen fear, or animate hope.

The *thunder houſe, fig. 3, pl. 2*, as it is uſually called, is the apparatus principally uſed to illuſtrate the Franklinian method of preſerving houſes from damage by lightning. It conſiſts of a mahogany board, ſhaped like the gable end of a houſe. It is fixed upright on an horizontal board as a ſtand; a ſquare hole is made in the gable board, into which is fitted, ſo as to go in and out eaſily, a ſquare piece of wood; a wire is fixed in the one diagonal of this board, and wires are alſo fixed in the gable board, one from the upper part, the lower end of which comes to one corner of the ſquare hole; the upper end of the other wire coincides with the oppoſite corner, and goes down to the bottom of the gable board. The upper wire has a braſs ball on the top; this may be occaſionally taken off, which leaves a point expoſed; at the bottom of the lower wire there is a hook; connect the hook at the bottom with the outer coating of a jar, place the ſquare piece in the hole, ſo that the metallic wire ſhall not coincide with the other two; when the jar is charged, bring the diſcharging rod from the knob thereof to the ball of the houſe; an exploſion will enſue, and the ſquare piece be driven out to a good diſtance from the gable board.

Put the ſquare piece into the hole, in ſuch a manner, that the ends of the diagonal may not coincide with the ends of the wire of the gable board, then make the diſcharge as before, *and the metallic circuit being now complete*, the ſquare board will remain in it's place.

Take off the ball, and the point will prevent an

an explosion, and it's accumulating therein in any sufficient quantity to do any damage.

The prime conductor is supposed to represent a thunder cloud discharging it's contents on some metal projection at the top of a building; and this is considered as receiving no damage when the conductor is perfect; but when the connection is imperfect, the fluid in passing from one part to the other, damages the building.

LECTURE

LECTURE XLIX.

ON THE NATURE OF ELECTRICITY, OF ANIMAL ELECTRICITY, &c.

AFTER pointing out to you the principal phenomena of electricity, and exhibiting to you many of the moſt intereſting and entertaining experiments in this branch of natural philoſophy; I ſhall now endeavour to trace out it's connection with the great agents in the operations of nature, and thus lead you to form ſome idea of what electricity is, and of it's uſe in the great ſyſtem of things. Whatever it may be, it is certain, and that without any exaggeration, that whether you look to the heaven above, or the earth beneath, you can ſcarce perceive any thing that is not acted upon, and in a manner perfectly ſubjected to the operations of this wonderful fluid.

That electricity is *real matter*, and not a *mere property*, is evident from a variety of circumſtances. When it paſſes between bodies, it divides the air, and puts it into thoſe undulations which give us the idea of *ſound*. It emits the rays of *light* in every direction, and thoſe rays are variouſly refrangible and colorific, as other light is: and, if light is acknowledged to be matter, it is contrary to reaſon and experience, to ſuppoſe that the thing which emits it ſhould not likewiſe be material; neither are the other ſenſes unaffected at it's preſence: it's *ſmell* is ſtrongly phoſphoreal or ſulphureous. The ſenſe of *feeling* is a witneſs of it's preſence, not only from the ſparks which, when received from the conductor of a powerful machine, are pungent,

pungent, and will paſs through two or three perſons ſtanding on the ground, but alſo from the ſhock. A ſtream of electric matter has alſo evidently a *ſubacid taſte.*

In contemplating the ſyſtem of nature, you perceive three kinds of fluids of extreme ſubtilty, and very much reſembling one another; theſe three are *fire, light*, and *electricity*. Their reſemblance is ſo great, that it is not ſurpriſing to find it the general conception of all uninformed minds, that they are ultimately the ſame; on examining the evidence of their identity, you will find it to be exceeding ſtrong.

If it be true, that natural effects are not to be aſcribed to *many* different means or agents, where *one* will ſuffice, theſe three ſhould be conſidered as different modifications or ſtates of the ſame fluid. *Light* or ſolar fire will *burn* in fuel, and act in ſolid matter with greater effect than the moſt violent fire of a furnace. *Common fire*, like that of the ſun, will promote vegetation and ripen fruits. The *electric fire* will light a candle, and fire gunpowder, like the common fire; will afford a ſpectrum of the 7 primordial colours in common with light; and will throw metals into fuſion with a violent ſcorching heat.* Let us leave generals, and deſcend more into particulars.

Theſe three fluids all agree in one property, that of exciting heat in certain circumſtances, and not doing ſo in others.

Fire, in the common acceptation of the word, always excites heat; but in it's *latent* ſtate, it lays aſide this property, and in vapour, for inſtance, is cold to the touch.

Light, when collected into a focus by a burning glaſs, i. e. when it's rays converge to a center, and diverge or attempt to diverge from one, produces heat,

* Jones's Phyſiological Diſquiſitions.

Electricity, when it's force is concentrated and converged, produces heat, as I ſhall ſoon ſhew you by it's effect on a thermometer. This does away the objection formerly made to thoſe, who aſſerted, that electricity was that elementary fire which pervaded all ſubſtances: the objection was, that though the electric matter emitted light, and had the appearance of fire, it wanted it's eſſential characteriſtic of burning; and where great quantities of the fluid were forced through ſubſtances, they inſinuated, that it might be occaſioned by the internal commotion excited among their ſmall particles.

There is no occaſion to dwell upon the weakneſs and fallacy of the objection, as it is completely removed by many facts. 1. The effect of electricity upon the thermometer. 2. By the experiment that was made at the Pantheon by Mr. Wilſon, with the immenſe apparatus that was conſtructed for making experiments on the preferable utility of pointed or knobbed conductors, for preſerving buildings from lightning. The electric aura from this machine fired gunpowder in the moſt unfavourable circumſtances that can be imagined, namely, when it was drawn off by a ſharp point, in which caſe it has generally the leaſt force. Upon a ſtaff of baked wood, a ſtem of braſs was fixed, which terminated at the top in a wooden point; this point was put into the end of a ſmall tube of Indian paper, made ſomewhat in form of a cartridge, about an inch and quarter long, and $\frac{2}{10}$ ths of an inch in diameter. When the cartridge was filled with common gunpowder unbruiſed, a wire communicating with the earth, was faſten- to the bottom of the braſs ſtem. The charge in the large conductor being kept up by the motion of the cylinder, the top of the cartridge was brought near to the conductor, ſo as even frequently to touch

touch the tin-foil with which it was covered. In this ſituation a ſmall faint luminous ſtream was frequently obſerved between the top of the cartridge and the metal. Sometimes this ſtream would ſet fire to the gunpowder the moment it was applied; at others it would require half a minute or more, before it would take effect. The difference in time was ſuppoſed to ariſe from ſome moiſture in the powder. Tinder was fired much more readily.

It now appears clearly, that the electric fluid moving through bodies, either in ſmall quantities, or with rapidity, or in very great quantities, will produce heat, and ſet them on fire: it ſeems therefore ſcarce diſputable, that this fluid is the ſame with the element of fire.

Theſe are far from being the only inſtances of their identity, for fire is brought into action by friction, as well as electricity. Fire dilates all bodies: the electric fluid has alſo a dilating power, which is evident from it's action on a thermometer, though, in general, the force with which bodies cohere together is greater than the dilating power of electricity.

Fire promotes and accelerates vegetation as well as germination. Electricity does the ſame.

Electricity, as well as fire, accelerates evaporation.

The experiments made by Mr. Achard on the eggs of a hen, and by others on the eggs of moths, prove that electricity, as well as heat, favours the developement of thoſe animals. The electric fluid, in common with fire, will throw metals into fuſion.

If ſubſtances, with equal degrees of heat, touch each other, the heat is diffuſed uniformly between them. In the ſame manner, if two bodies with unequal degrees, or different kinds of electricity, touch each other, an equilibrium will be eſtabliſhed.

If bodies of different kinds, and of equal degrees of heat, are placed in a medium of a different temperature, they will all acquire, at the end of a certain time, the ſame degree of heat. There is a conſiderable difference, however, in the ſpace of time in which they acquire the temperature of the medium: ex. gr. metals take leſs time than glaſs, to acquire or loſe an equal degree of heat.

On an attentive examination of the bodies which receive and loſe their heat ſooneſt, when they are placed in mediums of different temperature, they will be found to be the ſame which receive and loſe the electric ſigns ſooneſt. Metals, which become warm or grow cool the quickeſt, are the ſubſtances in which the electric powers unite moſt readily. Wood, which requires more time to be heated or cooled, receives and loſes electricity ſlower than metals. Laſtly, glaſs and reſinous ſubſtances, which receive and loſe ſlowly the electric fluid, acquire with difficulty the temperature of the medium which ſurrounds them.

If one extremity of an iron rod be heated red-hot, the other extremity, though the bar is ſeveral feet long, will become ſo warm in a little time, that the hand cannot hold it; becauſe the iron conducts fire readily; but a tube of glaſs, only a few inches long, may be held in the hand, even while the other end is melting. The electric fluid, in the ſame manner, paſſes with great velocity from one end of a rod of iron to the other; but it is a conſiderable time before a tube of glaſs, at one end of which an excited electric is held, will give electric ſigns at the other.

Theſe obſervations prove, that ſeveral bodies that receive and loſe with difficulty their actual degree of heat, receive and loſe alſo with difficulty their electricity.

The electric powers may be put in action by heat and cold. Mr. Canton procured ſome thin glaſs balls,

balls, of about an inch and a half diameter, with ſtems or tubes about eight or nine inches in length, and electrified them, ſome vitreouſly on the inſide, others reſinouſly, and then ſealed them hermetically; ſoon after he applied the naked balls to his electrometer, and could not obſerve the leaſt ſign of their being electrical: but holding them at the fire, at the diſtance of five or ſix inches, they became ſtrongly electrical in a ſhort time, and more ſo when they were cooling. Theſe balls would, every time they were heated, give the electric power to, or take it from other bodies, according to the vitreous or reſinous ſtate of it within them. Heating them frequently diminiſhed their power, but keeping one of them under water a week did not in the leaſt impair it. The balls retained their virtue above ſix years.

The *tourmalin* and many other precious ſtones are alſo known to acquire electricity by heat. The tourmalin has always at the ſame time a vitreous and reſinous electricity; one ſide of it being in one ſtate, the other in the oppoſite. Sometimes one ſide will at the ſame time poſſeſs both electricities. Theſe powers may be excited by friction and by heat; nay, even by plunging it in boiling water.

Many inſtances prove, that electricity is produced by *liquifaction.* Thus where chocolate is manufactured in large quantities, a vivid light is frequently ſeen flaſhing upon it's ſurface after melting, and it will alſo attract light ſubſtances, ſeparate pith balls, &c. When it had loſt this property, Mr. Henly found it might be reſtored by melting it together with a ſmall quantity of olive-oil. If ſulphur be melted in a glaſs veſſel, and taken out when cool, both it and the glaſs will be found ſtrongly electrified.

I have already ſhewn you, that electricity is produced by the *evaporation of water;* I ſhall now

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relate Mr. Read's * mode of performing this experiment. He *inſulates* a large hollow tin cone, containing about four ſheets of tin plates, with many yards of ſmall wires coiled up within it; one end of the wire is extended from the cone, to a very ſenſible electrometer. The cone and wire collect and condenſe the aſcending electrified vapour, as it quits the *inſulated* veſſel, containing the fluid. The electrometer connected with the cone, is vitreouſly electrified; that connected with the veſſel from whence the vapour aroſe, is in a reſinous ſtate.

Mr. Read has alſo, by burning different ſubſtances in inſulated veſſels, under his tin cone, ſhewn, that bodies, *in paſſing from a ſolid to a fluid ſtate*, produce the two electricities: the quantity obſerved, is in general very ſmall, on account of the intimate affinity between *flame* and *electricity*.

ACTION OF ELECTRICITY ON A THERMOMETER.

Inſulate a ſenſible mercurial thermometer, and place the bulb between two balls of wood, one affixed to the conductor, the other communicating with the ground, and the electric fluid, in paſſing between the two balls, *will raiſe the mercury in the thermometer conſiderably*. With a cylinder of about ſeven inches and a half in diameter, the fluid paſſing from a ball of lignum vitæ to a ball of beech, and thence to the ground, elevated the quickſilver in the thermometer, from 68° to 110°, repeatedly to 105°. The thermometer was raiſed from 68° to 85°, by the fluid paſſing from a point of box to a point of lignum vitæ; from 67° to 100°, from a point of box to a ball of box; from 66° to 100°, from

* Read's Summary View of Spontaneous Electricity, &c.

from a ball of box to a braſs point; from 69° to 100°, from ball to ball; the bulb of the thermometer being covered with flannel.

"*If then theſe fluids, fire, light, and electricity, which thus mutually, and in all reſpects, aſſume each other's properties, are not the ſame; experiment is a thing not to be depended upon, and the moſt obvious rules of philoſophiſing, adopted and approved by all parties, are no better than ſpecious deceptions.*"

More indeed need not be ſaid to any obſerver of nature; but it is neceſſary to accumulate proof, in order to leſſen the prejudices of modern philoſophers, who have altogether neglected to ſtudy and trace the great agents of nature. For theſe it may be neceſſary to point out other links, in which they may ſee the connection between *fire*, *light*, and *electricity*.

Thus as heat is diminiſhed, or bodies are cooled, electricity ſucceeds in it's place. All electric bodies, by heat, are rendered conductors, and can no longer be excited; but as ſoon as the heat is removed, their electric property returns.

Water is a conducting ſubſtance; by being frozen, it's conducting powers are leſſened; when cooled down to twenty degrees below 0 of Fahrenheit's ſcale, it becomes an *electric*, and will emit ſparks by friction, like glaſs. The atmoſphere is a natural electric; but by a certain degree of heat, it loſes in a degree this property, and becomes a conductor; nor is there any doubt that it's electric properties are increaſed in proportion to the degree of cold imparted to it.

Mr. Æpinus mentions ſome facts in a letter to Dr. Guthrie, which will illuſtrate this ſubject; they relate to phenomena that are known to take place in Ruſſia, when a great cold has continued for ſeveral weeks. Mr. Æpinus was ſent for, to ſee

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an uncommon phenomenon. On going into the apartment of Prince Orloff, he found him at his toilet, and that, at every time his valet drew his comb through his hair, a pretty ſtrong crackling noiſe was heard; and on darkening the room, the ſparks were ſeen following the comb in great abundance, while the Prince was ſo completely electrified, that ſtrong ſparks could be drawn from his hands and face; nay, he was even electrified, when he was only powdered with a puff.

A few days after, Mr. Æpinus was witneſs to a more ſtriking effect of the electric ſtate of a Ruſſian atmoſphere. The great Duke of Ruſſia ſent for him one evening in the twilight, and told him, that having briſkly drawn a flannel cover off a green damaſk chair in his bed-chamber, he was aſtoniſhed at the appearance of a ſtrong bright flame that followed, but conſidering it as an electrical appearance, he had tried to produce a ſimilar illumination on different pieces of furniture, and could then ſhew him a beautiful and ſurpriſing experiment. His Highneſs threw himſelf on his bed, which was covered with a damaſk quilt, laced with gold, and rubbing it with his hands in all directions, the young prince, who had then reached his twelfth year, appeared to be ſwimming in fire, as at every ſtroke flames aroſe all around him, darted to the gold lace border, ran along it, and up to that of the bed, even to the very top.

While his Highneſs was ſhewing this experiment, Prince Orloff came into the room, with a ſable muff in his hand, and ſhewed us, that by only whirling it five or ſix times round his head in the air, he could electrify himſelf ſo ſtrongly, as to ſend out ſparks from all the uncovered parts of his body. The inlaid floors had become ſo dry, as to form a complete inſulation.

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In the winter time, therefore, we muſt conſider the frozen ſurface of the earth, the water, and atmoſphere, as forming one electrical machine of enormous magnitude, for the natural cold of thoſe countries is often cold enough to cool water to more than 20 degrees below 0, and thus render it an electric. That ſomething of this kind is real, appears from the exceſſive bright aurora borealis, and other electric appearances far exceeding any thing in this country. In the ſummer time theſe appearances are not remarkable, but an exceſſive heat prevails from the long continuance of the ſun above the horizon. *The quantity of heat in ſummer being ſucceeded by a proportionable quantity of electricity in winter,* one can ſcarce avoid concluding, *that the heat in ſummer, or diſengaged fire, becomes electric fluid in winter, which going off through the celeſtial expanſe returns again to the grand ſource of light and heat, thus making room for the ſucceeding quantities which are to enliven the earth during the following ſeaſon.*

If the identity of light, fire, and electricity, be admitted, the ſource from whence the electric fluid is derived into the earth and atmoſphere is very evident; it can be no other than the *ſun, or ſource of light.* The vaſt quantity of light continually proceeding from the ſun to the earth, muſt in a great meaſure be abſorbed thereby; but from other operations in nature, it is prevented from remaining there; it is therefore in continual circulation, to make room for the new quantities continually coming from the ſun. It muſt however be obſerved, that as this fluid is variouſly combined, it cannot appear in it's natural form of fire or light, till it is diſengaged, and capable of receiving a motion ſimilar to what it had when proceeding from the ſun.

This change of matter into a different form, with

with the ſubſequent regeneration of it into it's primitive form, is, ſays Mr. Jones, one of the great ſecrets of nature, whereby the world is kept from decaying either with reſpect to it's matter or it's motion. By means of a *circulation* in matter, the laſting motions of nature are maintained, and it's ſtores unexhauſted.*

The experiments that I ſhall now lay before you, do in the ſtrongeſt manner prove the identity of the electric fluid and light, and that both are tranſmitted through electric as well as other ſubſtances; and that it is on the motion of this fluid, that tranſparency depends; that when this medium is at reſt, the body is opake; when ſet in motion, it becomes tranſparent.

LUMINOUS EXPERIMENTS.

To render an ivory ball luminous. Take a ſtrong ſpark through the center of the ball, and it will be illuminated throughout.

To obtain a crimſon coloured ſpark. Take a ſpark through a ball of box-wood, and it will appear of a beautiful crimſon, or rather a fine ſcarlet colour; or the ſhock may be paſſed through pieces of wood of different thickneſſes and denſity, which will afford a very ample field for obſervation and experiment.

To make a bottle of water luminous. Connect one end of a chain with the outſide of a charged jar, let the other end lie on the table, place the end of another piece of chain at about one quarter of an inch diſtance from the former, then ſet a decanter of water on theſe ſeparated ends, and, on making the diſcharge through the chain, the water will appear perfectly and beautifully luminous.

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* See Jones's Phyſiological Diſquiſitions, p. 51.

There is scarce any substance, fluid or solid, but what may be rendered luminous, by passing the electric fluid through it, and thereby separating the electric powers inherent in the body. In water, spirit, oil, animal fluids of all kinds, the discharge of a Leyden phial, of almost any size, will appear very splendid, provided you take care to place them in the circuit, so that the fluid may not pass through too great a quantity of them.

To perform this, place the fluid, on which the experiment is to be made, in a tube three quarters of an inch in diameter, and four inches long; stop up the orifices of the tube with two corks, through which push two pointed wires, so that the points may approach within one-eighth of an inch to each other; the fluid, in passing through the interval which separates the wires, is always luminous, if a force be used sufficiently strong; the glass tube, if not very thick, always breaks when this experiment succeeds. To make the passage of the fluid luminous in the acids, they must be placed in capillary tubes, and two wires introduced, as in the preceding experiment, whose points shall be very near each other. It is a well-known fact, that the discharge of a small Leyden phial, in passing over a strip of gold, silver, or Dutch metal leaf, will appear very luminous. By conveying the contents of a jar, measuring two gallons, over a strip of gold leaf, one-eighth of an inch in diameter, and a yard long, it will frequently give the whole a dazzling brightness. You may give this experiment a curious diversity, by laying the gold or silver leaf on a piece of glass, and then placing the glass in water; for the whole gold leaf will appear most brilliantly luminous in the water, by exposing it, thus circumstanced, to the explosion of a battery.

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* See Mr. Morgan's Paper, Phil. Trans.

The difficulty of making any quantity of the electrical fluid luminous in any body, increases as the conducting power of that body increases; because the two powers unite sooner in proportion to the conducting power, and consequently all electric signs vanish.

In order to make the contents of a jar luminous in boiling water, a much higher charge is necessary, than would be sufficient to make it luminous in cold water, which is universally allowed to be the worst conductor.

There are various reasons for believing the acids to be very good conductors; if, therefore, into a tube filled with water, and circumstanced as has been already described, a few drops of either of the mineral acids are poured, it will be almost impossible to make the fluid luminous in it's passage through the tube, as the two powers unite immediately.

The ease with which the electrical fluid is rendered luminous in any particular body, is increased by increasing the rarity of the body. The appearance of a spark, or of the discharge of a Leyden phial, in rarified air, is well known. But we need not rest the truth of the preceding observation on the several varieties of this fact; similar phenomena attend the rarifaction of ether, of spirits of wine, and of water.

Spark in rarified water, spirits of wine, ether, and acids. Into the orifice of a tube, 48 inches long, and two-thirds of an inch in diameter, Mr. Morgan cemented an iron ball, so as to bear the weight which presses upon it when the tube is filled with quicksilver, leaving only an interval at the open end, which contains a few drops of water. Having inverted the tube, and plunged the open end of it into a bason of mercury, the mercury in the tube stood nearly half an inch lower than it did in a barometer

rometer at the ſame inſtant, owing to the vapour which was formed by the water. But through this rarified water, the electrical ſpark paſſed as luminouſly as it does through air equally rarified.

If, inſtead of water, a few drops of ſpirits of wine are placed on the ſurface of the mercury, phenomena, ſimilar to thoſe of the preceding experiment, will be diſcovered, with this difference only, that as the vapour in this caſe is more denſe, the electrical ſpark, in it's paſſage through it, is not quite ſo luminous as it is in the vapour of water.

Good ether, ſubſtituted in the room of the ſpirits of wine, will preſs the mercury down ſo low as the height of 16 or 17 inches. The electrical fluid, in paſſing through this vapour, (unleſs the force be very great indeed,) is ſcarcely luminous; but if the preſſure on the ſurface of the mercury in the baſon, be gradually leſſened by the aid of an air-pump, the vapour will become more and more rare, and the electric ſpark, in paſſing through it, more and more luminous.

The brilliancy and ſplendor of the electric ſpark is always increaſed when it is compreſſed into a ſmaller compaſs. That is, a ſpark, or the diſcharge of a battery, which we might ſuppoſe equal to a ſphere one quarter of an inch in diameter, will appear much more brilliant, if the ſame quantity of fluid is compreſſed into a ſphere one-eighth of an inch in diameter. This obſervation is the obvious conſequence of many known facts; if the machine be large enough to afford a ſpark, whoſe length is nine or ten inches, this ſpark may be ſeen ſometimes forming itſelf into a bruſh, in which ſtate it occupies more room, but appears very faintly luminous; at other times, the ſame ſpark may be ſeen dividing itſelf into a variety of ramifications, which ſhoot into the ſurrounding air. In this caſe, likewiſe, the fluid is diffuſed over a large ſurface, and in proportion to the diffuſion, ſo is the faint-

nefs of the appearance. A fpark, which in the open air cannot exceed one quarter of an inch in diameter, will appear to fill the whole of an exhaufted receiver, four inches wide and eight inches long: but in the former cafe it is brilliant, and in the latter it grows fainter and fainter, as the fize of the receiver increafes. This obfervation is further proved by the following experiments.

Introduce two pointed wires into the vacuum, fo that the fluid may eafily pafs from the point of the one, to the point of the other; when the diftance between them is not more than the one tenth of an inch, in this cafe we fhall find a brilliancy as great as in the open air.

Into a Torricellian vacuum, 36 inches long, convey as much air as will fill two inches only of the exhaufted tube if it were inverted in water; this quantity of air will afford refiftance enough to condenfe the fluid as it paffes through the tube into a fpark, 38 inches in length. The brilliancy of the fpark in condenfed air, in water, and in all fubftances through which it paffes with difficulty, depends on principles fimilar to thofe which account for the preceding facts.

In the appearances of electricity, as well as in thofe of burning bodies, there are cafes in which all the rays of light do not efcape; and the moft refrangible rays are thofe which efcape firft or moft eafily. The electrical brufh is always of a purple or bluifh hue. If you convey a fpark through a Torricellian vacuum, made without boiling the mercury in the tube, the brufh will difplay the indigo rays.

To an infulated metallic ball, four inches in diameter, fix a wire a foot and a half long; this wire fhould terminate in four ramifications, each of which muft be fixed to a metallic ball half an inch in diameter, and placed at an equal diftance from a metallic plate, which muft be communicated by

metallic

metallic conductors with the ground. A powerful ſpark, after falling on the large ball at one extremity of the wire, will be divided in it's paſſage from the four ſmall balls to the metallic plate. When you examine the diviſion of the fluid in a dark room, you will diſcover ſome little ramifications, which will yield the indigo rays only: indeed at the edges of all weak ſparks, the ſame purple appearance may be diſcovered. You may likewiſe obſerve, that the nearer you approach the center of the ſpark, the greater is the brilliancy of it's colour.

The influence of different media on electrical light, is analogous to their influence on ſolar light, and will help us to account for ſome very ſingular appearances.

Let a pointed wire, having a metallic ball fixed to one end of it's extremities, be forced obliquely into a piece of wood, ſo as to make a ſmall angle with the ſurface of the wood, and to make the point lie about one eighth of an inch below the ſurface. Let another pointed wire, which communicates with the ground, be forced in the ſame manner into the ſame wood, ſo that it's point likewiſe may lie about one-eighth of an inch below the ſurface, and about two inches diſtant from the point of the firſt wire. Let the wood be inſulated, and a ſtrong ſpark, which ſtrikes on the metallic ball, will force it's paſſage through the interval of wood which lies between the points, and appear as *red* as blood. To prove that this appearance depends on the wood's abſorption of all the rays but the red; when theſe points were deepeſt below the ſurface, the red only came to the eye through a priſm; when they were raiſed a little nearer the ſurface, the *red* and *orange* appeared; when nearer ſtill, the *yellow*; and ſo on, till, by making the ſpark

ſpark paſs through the wood very near it's ſurface, all the rays were at length able to reach the eye.

"Previous to the diſcoveries that have been made in modern times, relative to the chemical effects of *light*, ſome *mathematical philoſophers* diſputed it's exiſtence as a particular fluid, and even that of *fire* itſelf; they crudely imagined, that the phenomena of light and heat were only particular modifications of the ſubſtances, in which they appeared; a kind of *vibration* of their particles, tranſmitted by means of a *medium*, as in the caſe of ſounds."

"They applied the mathematics to this hypotheſis, in order to explain ſome particular phenomena; and as every thing that appears to be deduced from *mathematical theorems*, eaſily ſeduces thoſe who do not apply themſelves to examine *data*, this *theory*, which effectually barred the road to the moſt important phyſical reſearches, met with many partizans: but *chemiſtry and meteorology* have now come in to terminate the controverſy; and there are at preſent very few philoſophers who do not agree, that *lucidity* and *heat* are the effects of two fluids, namely, *light* and *fire*, which produce thoſe particular phenomena whenever they *are at liberty*; but which at the ſame time may be ſo combined with other ſubſtances, as to lie hidden in them without producing theſe effects, till again ſet at liberty. By an attention to theſe great *agents*, the ſtudy of nature has proceeded with rapidity, and the preſent æra will probably on this account be as much celebrated in the hiſtory of ſcience, as thoſe in which *Paſcal* demonſtrated the *preſſure* of the *air* on bodies, and in which *Newton* diſcovered the principle of *gravity*."

"Our progreſs in the knowledge of the origin of bodies, has been much advanced in this age, ſince chemiſts and philoſophers have begun to examine their

their *volatile products*, in other words, the *elastic fluids*; but this would have been doing but little, had not the advances in other branches of natural knowledge led them to discover, that the phenomenon of *heat* proceeded from a particular *substance* susceptible of *chemical affinities*, namely, *fire*, the immediate cause of heat. Here then is a *substance* of the highest importance in the *composition of bodies*, which nevertheless escaped the attention of philosophers, while they only estimated and expressed the amount of their *products* by their *weights*. Is it possible for any one to suppose, that we have hereby discovered all the *imponderable* substances that enter into the composition of *natural bodies?*"

Ought we to neglect the phenomena of *lucidity*, while every thing announces to us that *light* is a chemical substance? This neglect is scarcely now to be apprehended, as philosophers are aware that great *chemical* effects may be produced by *imponderable* substances. The *phosphoric* phenomena of certain mineral substances indicate clearly that light enters as an ingredient in their composition. Wilson and Beccaria have shewn, that every substance in nature is more or less phosphorical; and you have just seen, that there is scarce any substance but what you may render luminous by separating it's electric powers.

The relation of these two *imponderable substances*, whose existence is now established beyond a doubt, is such as in many other instances is found to subsist between such substances as enter into the *composition* the one of the other. *Light* frequently does not sensibly act otherwise than as the cause of lucidity, or of *luminous* phenomena; and *fire* in the same manner, only as the cause of *heat:* but at other times fire, in producing *heat*, produces also in the end it's *luminous* effects; and in some cir-

cumſtances light, in making *viſible* the objects, by it's reflection contributes to produce *heat*. Theſe phenomena clearly indicate, that one of theſe ſubſtances contains the other, but that under certain circumſtances it may be ſo decompoſed, as to permit either of them to exerciſe it's own peculiar properties.

The moſt excellent Boerhaave, in his analyſis of *fire*, has ſo clearly eſtabliſhed the univerſality and importance of this element, and ſo ſtripped it of the myſtic dreſs, in which it was enveloped before his time, that one would have imagined it ſcarce poſſible for philoſophers to have reſolved ſo many of it's ſubtil effects to *occult* or *fanciful* properties; yet that ſuch has been the caſe, is evident from the ſlighteſt inſpection of modern theories. Again, though the moſt obvious phenomena in nature, and numerous experiments, tend to aſcertain beyond all doubt, that the matter of common light or fire pervades all nature, and fills all things; yet, as I have before obſerved, the whole has been overlooked as an accidental filtration that implied no conſequences, nor interfered with the various unintelligible properties of bodies, notwithſtanding it's acceſs to their innermoſt penetralia.

It is evident, that the natural omnipotence of light depends on the *ſun*; by him, in a *natural ſenſe*, the matter of fire, as his iſſue, is omnipreſent, and all-ſufficient. If the life of all things depends on the activity he communicates to them, is it not probable that it is the influence of the ſolar fluid, that generates and maintains that life, in all it's ſpecific characters, in every being according to it's kind? And that life, whether it be vegetable or animal, is ſuch as it is according to the ſtate of the fire in it; and that every dead thing is only ſo, becauſe it's fire is quenched? The ancient

cient philosophers affirmed, that the light of the sun, which gave life and motion to all things, must be in all things; they therefore conceived all things to be replete with this fluid.

Is it not highly probable, then,* that this terraqueous globe is only an accumulation of materials introduced into the boundless ocean of solar fluid for a theatre on which, under the direction and guidance of ALMIGHTY GOD, it may display it's inexhaustible energy and powers; the terrestrial mass being so disposed and arranged by it's DIVINE AUTHOR, as to become a seminal bed of materials, where *light and fire* may pierce, animate, and display an endless variety and succession of beings? This fluid extricates all the forms, and generates all the powers of nature, out of the materials provided for it to possess.

It is impossible to form any clear or distinct idea of the agency of the solar fluid in the air, in animals, in vegetables, &c. without considering it first more in general; nor can you properly have a view of the universal agency of the element productive of *fire*, *light*, and *electricity*, and it's importance to the animal frame, unless you take an enlarged prospect of it's action. Besides, knowledge often makes more rapid advances, by reasoning upon *known facts*, than by discovering *new ones*, which by their novelty too often lead to *hasty undigested* theories. In the disquisition upon these fluids, I have always an eye upon the doctrine of electricity; and the preceding as well as following experiments all concur in shewing the analogy that runs through nature; and you will find that electricity, though not in name, has been the doctrine of all ages. I shall therefore continue to treat of these wonderful fluids. Of all that are

* See Vol. 2, Lect. xxi. p. 462.

known in the univerſe, the mobility of the matter of light is the greateſt. There is not the ſmalleſt ſpeck of colour in the beams of the ſun, that does not obediently receive perpetual impreſſions from him in all lineal directions, by night as well as by day. The *ſun*, as the fountain of motion, is alſo *continually agitating* this fluid either radially, or obliquely, by the lateral ſhocks and friction of the radii upon thoſe parts of the fluid that lie out of the line of the ſun's irradiation; theſe, together with the conſtant viciſſitudes of day and night, preſerve a conſtant motion in all it's internal parts.

But even this is inadequate to convey to you a juſt idea of the conſtant, poſitive, intenſe energy, from the activity of the matter of light. Of this you will form a better idea, by examining the mode of it's action in the interior parts of the moſt rigid and ſolid bodies. For in the moſt ſecret receſſes of the moſt ſolid and paſſive ſubſtances, the matter of light is ſo far from exiſting in an indolent quieſcent ſtate, that it is impoſſible to form an adequate idea of *it's inceſſant* and *active energy*, under theſe circumſtances. Yet this ſtate of bodies is but little thought of by philoſophers in their reſearches into it's properties, either common or ſpecial; which I ſhall illuſtrate, by conſidering the caſes of ſonorous bodies, and the phenomenon of hammering cold iron, red-hot.

If this fluid reſided within bodies, in an indolent and paſſive ſtate, it could exert no reluctation on any mechanical force, diſturbing it's paſſive occupation within bodies; whereas, in fact, it's natural ſtate is never diſturbed without an active irritation being excited in the fluid, to recover and repoſſeſs it's organical and interſtitial inherency, greater than that by which it was expelled; it returns with a force not barely ſufficient to recover

recover the dimenſions it occupied within bodies, but with a violence capable of expanding them as much beyond their natural ſize as the external blow or concuſſion tended to compreſs them within it: hence a vibratory colluctation takes place between that action which preſerves bodies in their natural craſis, and the rapid returns of the fluid to it's natural ſtate; theſe vibrations continue for a time, and die away imperceptibly.

This intenſe agitation, excited by the colliſion of bodies, is not confined to their points of contact, but pervades their whole ſubſtance, and oſcillates in every part. This is demonſtrated to the eye and ear, when a muſical chord is ſtruck. You have ſpecimens alſo of it, in all elaſtic ſonorous bodies. When a bell is ſtruck, the ſound continues labouring in the ear for a conſiderable time afterwards; nor is the tumult ſubſided, when our ſenſe of it fails; it paſſes through a gradual decay below the ſtandard of ſenſe.

Suſpend an iron poker from the head, by the teeth, and the iron diſcovers no great degree of any ſonorous quality; yet if it be ſtruck, you will have a very ſtriking ſenſation of the vibratory motion it's whole ſubſtance conceives from the ſtroke, by the teeth's tranſmiſſion of their feeling to the ear.

Phyſicians talk of the *irritability* of *our nervous ſyſtem*, as a very myſterious and wonderful phenomenon; but there are more ſtriking examples of this irritability in the moſt rigid dead ſubſtances. Subſtances, ſuch as glaſs, bell metal, &c. which are ſo rigid that few inſtruments will make an impreſſion on them, yet are capable of being agitated through every atom of their ſubſtance; nay in ſome caſes to be burſt in pieces by the impreſſion of certain ſounds. A wine glaſs will burſt in pieces by the action excited through

it's ſubſtance by certain tones of voice: columns of marble or porphyry are tremulous to *thunder exploſions*, and certain *tones* of an organ.

This exceſſive mobility of parts throughout the whole ſubſtance of the moſt rigid bodies, clearly implies *a great turgency of their ſubſtance with ſome very active fluid*, ſo that a ſmall increaſe of it's action is ready to burſt them in pieces. A ſlight reſiſtance to the internal agitation of a bell, will cauſe it to crack.

Now it is impoſſible to conceive, that ſuch a tremulous motion ſhould be produced through the whole continuity of ſuch hard bodies, unleſs they contained in themſelves ſome inconceivably *active element*, exerting a conſtant niſus to force their parts to as great a diſtance from each other as poſſible, and barely counteracted by the power that maintains their coheſion.

The ſymptoms of this *reſtleſs activity* within ſolid bodies, are not confined to ſuch as are commonly called elaſtic. Thus iron yields more ſtriking proofs of this latent active principle, than any ſubſtance of greater elaſticity than itſelf, and thus diſcloſes to our ſenſible conviction, preciſely what that principle or reſtleſs element is, that exerts it's energy ſo powerfully within all terreſtrial bodies.

For the *power* within bodies, that ſuſtains and preſerves their form, *is not a paſſive power*. It is a poſitive re-action to the approach of the parts of the body. The *law* of re-action being equal to action, reſides ultimately in the conſtitution of this powerful fluid medium. Whenever the ſpaces it occupies within the ſurface of bodies are preſſed nearer one another by any ſudden ſhock or colliſion, and conſequently this medium be for an inſtant driven out, the next inſtant it returns with violence, not enough to regain it's place in the body,

dy, but equal to that with which it was ejected; and therefore in returning, it dilates it's spaces as much beyond their sizes, as they were compressed below their natural standard by their collision; by which means, a temporary oscillation is excited between the efforts of that power, which circumscribes bodies, and binds them to their natural sizes, and the internal medium, which was irritated by the stroke, to act with a force equal thereto.

If the strokes, which dispossess this fluid of the spaces it naturally obtains within bodies, are quickly and successively renewed, before the colluctations raised by the former ones have subsided, the internal agitation may thereby soon be raised to such a height, as to break forth and manifest itself in the form of actual fire.

Every material being through all the forms of nature, is a composition of this celestial fluid and terrestrial matter; you will find the distribution of *material substances* into these *two classes* to be the real key to all *natural* knowledge; it not only distinguishes this globe from the celestial fluid in which it swims, but is to be applied to every individual terrestrial substance; which must be considered, if you would comprehend the phenomena of nature, as an intimate composition of these two elements; the latter being the organ or case to the energy of the former, and the modifier of it's incessant activities, while the former is the medium used by *mind* to impress those characters on the latter, which are known as the distinguishing properties of different bodies.

This fluid, according to the variety of the phenomena by which it's energy has been discovered to us, has been called under different circumstances *light*, *fire*, *electricity*, *materia subtilis*, *materia media*, *&c.* At other times it has been divested

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of it's materiality, and been confidered merely as a principle annexed to or inherent in matter, under the terms of *occult quality*, *nifus*, *attraction*, *electric attraction*, *elafticity*, *irritability*, *ftimulus*, *fympathy*, *vital principle*, *life*, &c. &c.

This invifible fire is ever ready to exert and fhew itfelf in it's effects, cherifhing, heating, fermenting, diffolving, fhining, and operating in various manners, according to the fubjects which employ and determine it's force. It is prefent in all parts of the earth and firmament, though in moft cafes latent and unobferved, till fome occafion produces it in act, and renders it's effects vifible; it exifts in our conftitution, and indeed in every form in nature in two modes, interftitially and organically. If the pores of gold (which is one of the denfeft known fubftances) exceed it's folid or earthly parts, how much greater muft the proportion of folar fluid be in our frame than in that of gold! To illuftrate this, I fhall refer to the element of water.

Now *water*, by it's *tranfparency*, certifies to your fenfes that *light* has free accefs into and through it's fubftance; and it probably fills up it's interftices, as water does a fpunge when foaked in it. But we know further by the fluidity and the volatilifation of water, that the matter of light or fire has not only accefs to it's interftices, but penetrates and occupies it's fimilar elementary particles; for thefe particles could not be rendered volatile, but by internal dilatation, nor could they be dilated, but by fomething that reached their internal parts.

Thefe particles then are the organical parts of water, which have their individuality as feparable elementary parts, as well as their fimilarity of character, preferved by that etherial principle that poffeffes them.

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These points being cleared, you will now have an obvious ſolution of the difficulties which have attended the queſtion, What is the principle of natural life? *Modern phyſiology* has indeed bewildered the conception of it's pupils, by not diſtinguiſhing between the term *life*, uſed *metaphyſically* for our ſyſtem of *conſciouſneſs*, or as the reſult of our whole compoſition explicable only by the *creator*, and the ſame term *life*, uſed *phyſically* to denote the *natural power* that preſides in reciprocally regulating, and being regulated by the mechaniſm and diſpoſition of the whole, and of every part and particle of our corporeal frame.

It is by the unremitting reciprocal corruſcations of this vital principle in the fluids and ſolids, according to the different qualities and conſiſtencies they aſſume in different parts of our conſtitution, that the whole ſyſtem of life is diſplayed and maintained in every individual. *Light* is not more inſtantaneouſly diſpatched by reflection from a mirror, or by that power which every point of the air has of reflecting lightning, than that with which the ſame fluid, under the character and modification of the vital principle, acts from place to place in the human frame.

For the moment of *willing*, and *moving* any member is, undiſtinguiſhably the ſame; ſo likewiſe the moment of being *touched*, and the touch being *felt*. But theſe inſtantaneous tranſmiſſions in our frame, are not confined to ſuch as we have a conſcious perception of: they are inceſſantly tranſacting; the remoteſt vibrating artery correſponding with the heart, does not more immediately and conſtantly feel it's power, than the material principle of vitality through it's whole form in our ſtructure, feels the permanent influence of it's own power concentered in and irradiating from the brain, *the nerves being the directors of the various intend-*

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ed energy of the powers of natural life. This vivifying plenum, occupying and organiſing every particle and interſtice in our compoſition, can diſcharge it's whole niſus according to the pathic intimation and direction of any nerve or nerves, as inſtantly as *electricity* does through the ſubſtance of the body that receives the ſhock.

When you conſider the rarifying and expanſive force of this element, which is capable in an inſtant of time to produce the greateſt and moſt ſtupendous effects, you have a full proof not only of the power of fire, *but alſo of the wiſdom with which it is managed*, and withheld from burſting forth to the utter ravage and deſtruction of all things; and it is very remarkable, that this ſame element, ſo *fierce* and *deſtructive*, ſhould yet be ſo variouſly tempered, and applied by Divine Providence, as to be the *genial* and *cheriſhing flame of all natural life.*

So bright and lively are the ſignatures of a DIVINE MIND operating and diſplaying itſelf in fire and light throughout the world, that, as Ariſtotle obſerves, " all things ſeem full of divinities, whoſe apparitions on all ſides ſtrike and dazzle our eyes." And indeed the wiſeſt men of antiquity, how much ſoever they attributed to ſecond cauſes, and the force of fire, yet ſuppoſed it always to be governed by a *mind* or *intellect* active and provident, reſtraining it's force, and directing it's operations.

The *order* and courſe of things, together with what we daily experience, fully proves that there is a *mind* that governs and actuates this mundane ſyſtem, as the *proper real agent* and cauſe, and that the inferior *inſtrumental* cauſe is *pure ether*, *fire*, or the ſubſtance of *light*, which is applied and determined by an infinite *mind* in the *macrocoſm* or univerſe with unlimited power, and according to

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ſtated rules, as it is in the *microcoſm* with limited power and ſkill by the *human mind. There is no proof from reaſon, or experiment, of any other agent or efficient cauſe than* MIND *or* SPIRIT. When I ſpeak therefore of corporeal agents, or corporeal cauſes, you are to underſtand them as uſed in a different, ſubordinate, and improper ſenſe.

The *principles,* whereof a thing is compounded, the inſtrument uſed in it's production, and the *end* for which it was deſigned, are all in vulgar uſe termed cauſes, though none of them be, ſtrictly ſpeaking, agent or efficient. Therefore when I ſpeak of the *element of fire as acting, it is to be underſtood only as a mean or inſtrument,* which is indeed the caſe of all mechanical cauſes whatſoever. They are nevertheleſs ſometimes termed *agents,* or cauſes, although by no means *active,* in a ſtrict and proper ſignification: when therefore *force, power, virtue,* or *action,* are mentioned as ſubſiſting in an extended, corporeal, or mechanical being, theſe terms are *not* to be taken in a *true, genuine, real,* but only in a *groſs* and popular ſenſe, which ſticks in *appearances,* and does not analyſe things to their firſt principles. In compliance with eſtabliſhed language, and the uſe of the world, we muſt employ the current phraſes; but for the ſake of truth, we ſhould diſtinguiſh their meaning.*

What I have here, as well as in my former Lectures, laid before you, concur in proving, (nay all nature gives teſtimony thereto,) " that the fluid etherial matter of the heavens acts by impulſe on the ſolid matter of the earth; is inſtrumental in every one of it's productions, and neceſſary to all the ſtated *phenomena* of nature. The elements may then be divided ino *active* and *paſſive*; not that they are ſuch by any *inherent* or *eſſential* difference, but

* Siris, No. 154, 155.

but that, according to the order eſtabliſhed by the DIVINE ARCHITECT; they are obſerved to ſubſiſt under ſuch relations."*

OF ANIMAL ELECTRICITY.

I ſhall here introduce you to the reaſons and experiments, which induced Dr. Shebbeare to adopt electricity, as the principle of vital heat and motion, in 1755; and then ſhew how far his opinion has been confirmed by ſubſequent information.

A muſcle put into motion by the will, may yet be more actuated by a farther extenſion of volition, as from walking to running; by this operation of the mind, there is more of the vital fire determined to the muſcles employed in thoſe actions; muſcles are alſo brought into action, by the fire from the electric machine, and palſied limbs have been rendered plump by the ſame machine, and a power of motion and action reſtored to thoſe whoſe palſies have not been of a long ſtanding, and which do not take their ſource from the ſpinal marrow. This offers a convincing proof, that vital fire is the cauſe of muſcular motion, and that this vital fire is of the ſame kind with that produced by our electrical machines.

After ſo many experiments on the *electrical* fluid, and after the diſcovery of ſo many phenomena, which are no ways to be diſtinguiſhed from thoſe of *fire*, it will ſcarce be any longer diſputed, that they are the ſame in their own nature. Nor will any one, I preſume, after the fire put in action in electrical experiments, has been perceived by all our ſenſes, ſuppoſe that there can be leſs reality in it, than in earth, air, water, or fire, whoſe reality with reſpect to mankind depends on the

* Jones's Eſſay on the Firſt Principles of Philoſophy, p. 8.

the evidence of thoſe very ſenſes. Electricity communicates ideas to every ſenſe; it is light to the eye, odour to the noſe, ſtroke to the touch, ſub-acid to the taſte.

If you apply *heat*, either by means of water, or any other method, to the heart of a viper or of an eel taken from the body of thoſe animals, it will again begin to vibrate. Now *heat* is fire in action, and thus you ſee the ſame effect is produced, as was effected in the palſied limb.

The reaſon why the hearts of vipers, and eels, and ſuch like animals, are put into motion by a power of the ſame nature, though in a leſs degree than that which moves the hearts of larger animals, is, becauſe they are extremely cold by nature, and therefore a leſs degree of fire actuates on their heart than on thoſe of larger animals. It is not improbable, that the ſame degree of heat, which is neceſſary to keep a fowl alive, would deſtroy a frog or viper, and burſt the cells of the tunica cellularis. After the heart of a viper has diſcontinued to beat with the application of any certain degree of heat, it will vibrate again on the application of a ſuperior degree.

The heart, which in the open air had ceaſed to move with a certain degree of heat, will vibrate again in vacuo with the ſame degree; for the preſſure of the atmoſphere being removed, a leſs power is required to diſtend the fibres.

Dr. Shebbeare took the heart of an eel, which had been ſome time dead, and placing it on a card, put it on the conductor; the firſt motion that was communicated to it, was it's ſwelling, or the diaſtole of the ventricles, which not being immediately followed by the contraction or ſyſtole, he took the electrical ſpark therefrom, on which it contracted; it then dilated again, and upon the application of his finger again contracted; and thus having

having repeated it ſeveral times, the heart continued to perform it's diaſtole and ſyſtole, without being touched; and when it was removed it ceaſed, but began again upon being placed on the bar.

Lord Bacon has given us a very remarkable inſtance of the effect of fire upon the human heart. He ſays, "that upon the embowelling of a criminal, *he* had *ſeen* the heart of a man, after it was thrown into the *fire*, leap up for ſeveral times together, at firſt to the height of a foot and a half, and then gradually lower, to the beſt of his memory, for the ſpace of ſeven or eight minutes."

Trace vital heat and motion from their ſource, and you will find theſe phenomena ſtill more clearly illuſtrated. An egg, though it include all the parts neceſſary for the formation of an animal, will never produce a chicken, unleſs it is kept in a certain degree of heat for a certain time; which heat, regularly conducted, is all that is neceſſary to the production of an animal ſimilar to the parent.

That there is nothing more neceſſary to the producing this animal from an egg, than *common fire*, has been long known and practiſed in Egypt, and demonſtrated by Mr. Reaumur. There is no other vital principle transfuſed from the hen to the embryo, than from a common fire. Thus is fire plainly proved to be the firſt mover in the animal machine, and is the only active material or natural principle during it's exiſtence; and it is a principle abſolutely neceſſary for the preſervation of health, and generating wholeſome fluids. Shall fire be allowed to have the power of beginning the vital motion in the womb, or egg, and ſhall it be refuſed the power of continuing it after the birth?

Now, for many reaſons which will be ſeen as we proceed, it appears that the fluid of fire paſſes by the nerves to the brain and ſpinal marrow, and from

from thence to the heart for the ſupplying the cauſe of involuntary motion, and that a ſufficient quantity is always detained there to go to the muſcles at particular times for the performing voluntary motion.

This *fire* (the reality of whoſe exiſtence is proved by *all the demonſtrations* which can attend the proof of any exiſtence, and whoſe general properties are now well known) is lodged in the brain, medulla ſpinalis, ganglions, and nerves, and thence operates on all the different parts of the body. The diminution and waſte of this fire is continually ſupplied from the earth.

The nerves, which are deſtined to the ſenſe of feeling, are the conductor of this fire to the brain; while thoſe which are deſtined to motion, are the conductors by which it is conveyed to the muſcles. For a particular explanation of the manner in which it acts, I muſt refer you to Dr. Shebbeare's maſterly performance.

It is not the fluid of fire alone, that conſtitutes and preſerves the vital heat and vital motion; but it muſt for this purpoſe be brought into a certain ſtate or degree of action, which, in a healthy man, amounts to 98 of Fahrenheit's thermometer; and according to the degrees of heat originally deſtined to each animal, and the exceſs or decreaſe of it, will be the ſtate of it's activity and health.

Nor is this confined to animals; ſomething of the ſame kind ſeems to take place in vegetables. The heat which produces an apple to perfection, would never bring forth a pine apple, and the firs which thrive and look green on the bleak and ſnowy hills of Norway, would periſh in the burning ſands of Barca; whilſt the ſpicy vegetables of the eaſt, which breathe inceſſant ſweets amid the glowing ſoil of Arabia, would languiſh and expire in that cold clime which breeds the lofty oak.

The

The heat which hatches the chicken from an egg, would deftroy the whole race of fifhes if it affected their fpawn; and thus the very fame element, which makes an animal complete in one degree, and in one fpecies, deftroys it's exiftence in another fpecies with the fame degree.

The degree of heat, which would injure the life of a frog, would not be fufficient to keep the heart of a fheep in action. *Health* depends on a degree of heat which is natural to each animal, and which was firft imparted to it by that DIVINE INTELLIGENCE, who is alone able to actuate and inform, and who has furnifhed us with powers to keep up this degree, and counteract and throw off a greater.

In this account of vital heat and motion, there is nothing new fuppofed; no new property affigned either to fire or electricity; no new formation given to any part of the human body.

We require no more of the *nerve* than that it exifts, and that it be a conductor of the electric fluid; which experiment proves, vital heat and vital motion are here as they are in nature, beginning together, and continuing fo through life. *Solar fire* and the *electric fluid* are one and the fame vivifying principle, actuating all the different orders of material beings: they are fo radically the fame, that in various inftances you find that what was one becomes the other; and thus facts and philofophy are united; and the caufe of natural life and motion is difcovered by reafon and experience to be the fame with what our fenfes inform us to be intuitively the true one. And permit me to tell you, that in general, whenever the account given to explain the caufe of any phenomena in nature, is contradictory to the obvious apprehenfion of the fenfes of a plain underftanding, there is reafon to fufpect it's truth. That to the agency of fire all animal

animal motion and animal heat are owing, is obvious to the meaneſt capacity; and if this element ceaſe to act, or if it be diſunited from the body, death is the certain conſequence. Every part of nature affords facts to ſupport this opinion. Contemplate the great luminary which enlightens the univerſe, and you will find every ray is fraught with fire, which it is ready to manifeſt on meeting a proper recipient. Without the genial warmth they communicate, both *animal* and *vegetable* life muſt ceaſe, and all nature become one lifeleſs, torpid, diſmal ruin.

All nature bears teſtimony to the exiſtence of this etherial fluid, and to it's inceſſant active energy. To us, indeed, it often remains *latent*; and peculiar circumſtances are neceſſary to excite thoſe ſigns which render it's effects moſt viſible to our ſenſes. The ancients, viewing nature as ſhe is, often attained more accurate notions of her operations, than modern philoſophers. Theſe, by multiplying experiments without firſt attaining a correct idea of the facts continually preſented for obſervation in the great laboratory of nature, have often waſted their time and talents; and in the end have bewildered themſelves in an inexplicable labyrinth, or at beſt, have only placed one ſpecies of ignorance in the deſerted room of another.

The Platoniſts and Pythagoreans maintained, that *fire* was the great inſtrumental cauſe in the univerſe, ſubordinate to the *infinite creative mind*; and that it actuated the *macrocoſm*, and animated the *microcoſm*.

The old naturaliſts have univerſally maintained, that fire was in all bodies; and however indiſtinctly they were able to write of it, what they wrote was true. Theophraſtus has ſpoken of fire in terms that beſpeak a conſiderable knowledge thereof. Far from ſuppoſing *motion* to be the

caufe, much further from fuppofing it to be the effence of fire, he afferts, that fire is a very diftinct thing from the matter in which we fee it lodged, and from the motions which we fee excite it; and that it is, in it's pure natural ftate, fine, etherial, imperceptible, and at perfect reft. He hints, that this fire was the breath which the creator diffufed in all matter, which, paffing over the waters, made out of them metals, ftones, and earth; and afferts, that it is the inftrument which he employs to give all things life and motion.

They in general confidered *earth* and *water*, *air* and *fire*, as the component elements of all vifible and known corporeal beings, and that life was conveyed to them through the elements of air and fire; that this fire was continually operating to apply and adjoin to thefe bodies the newly arrived matter, converting this matter into a fubftance of the fame nature or form, with that part to which it was applied, and thus fitting it for the *growth* or *increafe*, as well as the aliment of the part. But then they alfo confidered *natural life* as only poffeffed of thefe powers, becaufe it was the immediate agent of *mind*: for *mind* is evidently the *caufe of form* to all things formed by *man*; and the caufe of *union* or *conjunction*, to all things united or conjoined by art.

It is hardly poffible not to agree in many refpects with thefe ancient fages: for when you look round with a philofophic eye, and contemplate the univerfe with fedulous attention, you will find, that there is no effect either *beautiful*, *great*, *marvellous*, or *terrible*, but what proceeds from *fire*.

It can therefore be no matter of furprife, that after the difcovery of electricity, it was confidered as the *phyfical* caufe of motion, irritability, &c. but it is furely a fubject of regret, that *medical* men have fhewn fuch reluctance to the inveftigation of this

this ſubject, and that too many have in every poſſible way endeavoured to diſcountenance it's application in medicine; though *the agency of this fluid*, and *it's exiſtence in animated nature*, has been ſo fully proved by a variety of experiments, that there can be very little doubt, that it is eſſentially connected with, and continually exerting it's influence on the human frame. I ſhall here lay before you ſome further inſtances to corroborate what has been already advanced. By means of a ſmall condenſing plate, Mr. Cavallo obtained very *ſenſible ſigns* of electricity from various parts of his *own body*, and the *head of almoſt any other perſon*. The ſtrong electricity obtained in froſty weather from ſilk ſtockings, &c. on being pulled off, as well as that obtained by combing the hair, have been long known. Among others, Mr. Brydone mentions a lady, who, on combing her hair in froſty weather in the dark, had obſerved *ſparks of fire* to iſſue therefrom. This made him think of trying to collect the electrical fire from human hair alone. To this end, he deſired a young lady to ſtand on wax, and comb her ſiſter's hair, who was ſitting in a chair before her; ſoon after ſhe had begun to comb, the young lady on the wax was ſurpriſed to find her whole body electrified, and darting out ſparks of fire againſt every object that approached her. Her hair was ſtrongly electrical, and affected an electrometer at a conſiderable diſtance. He charged a metallic conductor from it, and in the ſpace of a few minutes collected a ſufficient quantity of fire to kindle common ſpirits, and, by means of a ſmall jar, gave many ſmart ſtrokes to all the company.

When the diſcoveries in this ſcience, ſays Mr. Brydone, are further advanced, we may find, that what we call ſenſibility of nerves, and many other diſeaſes, which are known only by name, are

owing to the bodies being poſſeſſed of too large or too ſmall a quantity of this ſubtil fluid, which is perhaps the vehicle of all our feelings. It is known, that in damp and hazy weather, when this fire is blunted and abſorbed by the humidity, it's activity is leſſened, and what is collected is ſoon diſſipated; then our ſpirits are more languid, and our ſenſibility is leſs acute. And in the fierce wind at Naples, when the air ſeems totally deprived of it, the whole ſyſtem is unſtrung, and the nerves ſeem to loſe both their tenſion and elaſticity, till the north-weſt wind awakens the activity of the animating power, which ſoon reſtores the tone, and enlivens all nature, which ſeemed to droop and languiſh in it's abſence: nor can this appear ſurpriſing, if it is from the different ſtate of this fire in the human body, that the ſtrictum and laxum proceeds, and not from any alteration in the fibres themſelves, or their being more or leſs braced up, (among which bracers cold has been reckoned one,) though the muſcular parts of an animal are more braced when they are hot, and relaxed when they are cold.

From the perpetual electricity of the atmoſphere, which is no longer a problem, as it's exiſtence and agency in that maſs of air which ſurrounds our globe, has been aſcertained by numerous, clear, and deciſive experiments, it ſeems but juſt to infer, that it muſt exert a certain influence on all the beings contained therein, and principally on organized bodies, among which the human frame claims the pre-eminence.

But there is no neceſſity for deductions from a general view of nature, for we are now in poſſeſſion of facts, which prove, that it is a principal agent in promoting the functions of animated beings; as in the gymnotus electricus torpedo, and ſilurus electricus. For the ſimilitude eſtabliſhed

between

between the electrical fluid of these animals, and that of nature at large, is such, that in a physical sense they may be considered as the same.

Of the later Experiments on Animal Electricity.

When Mr. Walsh first attributed the sensations produced by the torpedo, &c. to electricity, his opinions, and the inferences deduced from his experiments, were vehemently opposed by most of the best electricians of the day: the conceptions of these men being limited to the minutiæ of experiments, they were incapable of grasping a more extensive subject, or one that was not in all respects conformable to the *appearances* they were used to. Whereas a just view of things should have prepared them to expect various anomalies, while they were investigating the nature of *an invisible* and subtil agent, subject to a variety of modifications from the substance through which it passes, or with which it may be combined. Hence in the pursuit of animal electricity, you must not expect to meet with every electric sign, as from the very nature of it's connection with animated beings, it will certainly acquire properties that are not to be found when it is disengaged therefrom.

Before I relate any of the experiments of Valli, &c. I shall lay before you those principles which I conceive will throw great light on the subject of animal electricity, and by which they may be reconciled to the general agency of nature. You have seen by a great variety of experiments, that electricity is always *first* rendered sensible by a *solution of continuity*; you have also every reason to suppose, that the *electric matter* is carrying on it's most important functions, when we are *unable*

to perceive any ſigns of electricity; you have ſeen that the *electric matter*, and what we term *electricity*, are not inſeparable beings, that the *one* may ſubſiſt, when the other ceaſes to appear. As the air may occupy a ſpace without producing ſound; ſo the electric matter may reſide in a body, *without exhibiting any electric ſigns*. We know alſo by univerſal obſervation, as well as partial experiments, that there is a principle in all bodies, which is continually endeavouring to extend their form, but whoſe energies are continually counteracted by an exterior force. Now it muſt be evident, that every ſolution of continuity will give an opportunity for this *expanſive, dilating* ſubſtance to eſcape, when it puts on new and unexpected appearances. Now as we know this expanding ſubſtance is fire, and have a proof, that on it's eſcape it exhibits electric ſigns, we have a further confirmation of the identity of theſe elements.

I think this view of the ſubject is in itſelf a ſufficient refutation of Dr. Munro's attempt to prove, that the nervous fluid or energy is not the ſame with the electrical;* though many other arguments may be adduced to anſwer the ſame purpoſe.

His difficulty in conceiving how the electrical fluid can be accumulated within our nervous ſyſtem is not greater than that of conceiving how it is accumulated amidſt a conducting fluid in the torpedo, &c.; nor indeed than of it's being accumulated in the Leyden phial, as glaſs is now known to be permeable thereto. But the difficulty with reſpect to animals vaniſhes, when we conſider that *electrical appearances are occaſioned by a ſtate of the fluid altogether different from that under which it exiſts in the animal frame*; when it is in the latter, it's

* Munro's Experiments on the Nervous Syſtem.

it's powers are united, and it's operations imperceptible; when it appears as electricity, it's powers are divided, and some of their effects rendered sensible.

So far as *mechanical stimuli* have any relation to *fire*, so far they will be in some degree similar to the *electrical fluid*, and act in the same manner; for stimulants act only as they are the vehicles of fire. The second objection therefore of the professor falls to the ground. The same reasoning applies to his sixth objection.

His fourth reason, so far from proving that the nervous and electrical fluids are not the same, may be considered as a clear proof of their identity, for the two electrical powers always act in opposite directions.

On the same principle the nervous energy (the electrical fluid in it's united state) cannot pass readily up or down a nerve that has been tied or cut, for the tying or cutting the nerve changes the state of the fluid.

Before I proceed to give you an account of the experiments relating to animal electricity, I shall lay before you some remarks of the Rev. Mr. William Jones,* from whom we have already profited so much in the course of these Lectures, and which are intimately connected with our subject. "As the force of the electrical fluid (says he) is principally exerted on the *nerves* and *tendons* of the body, there is reason to believe that this fluid is the same with that *something*, which many physicians have discoursed upon, under the name of *animal spirits*. The nerves do not appear as if they were designed to admit any animal fluid or liquor, unless it be an indolent lymph necessary to

* Jones's Essay on the First Principles of Natural Philosophy, p. 266.

keep them moiſt: but their pellucidity indicates that they are properly adapted to give a direct paſſage to the fluid *light*; for they are tranſparent, and that not tranſverſely, but longitudinally, or in the direction of their fibres. This Mr. Jones obſerved accidentally, as ſome eyes of ſheep and oxen, which he had procured for diſſection, lay on the table; one of theſe eyes *ſhone* in the day time, much in the ſame manner as the eyes of ſome animals do in the dark; on examining into this circumſtance, he found that if his hand were interpoſed between the neareſt window and the extremity of the optic nerve (a part of which, nearly an inch in length, remained with the eye, and was accidentally pointed towards the window) the light immediately diſappeared."

From this he was led to conſider, whether the *light* that appears in the eyes of ſome animals in the night time, is really a *reflection* of light from the eye, as is commonly ſuppoſed; or whether it does not rather *paſs into the eye, through the optic nerve, from the body of the animal?* It is not eaſy to conceive how this ſhining can be occaſioned by a reflection of light from the choroides in the bottom of the eye, when the light to be reflected (as in a dark night) is not viſible before it's entrance into the eye. If a candle be held before the eyes of a dog, and you place yourſelf in the line of reflection, the light will be viſibly reflected from his eyes, becauſe the illumination is ſufficiently ſtrong: but when there is no viſible illumination at all, how ſhould it account for the like effect? Whence it is more reaſonable, that this appearance ſhould be owing to a light from within the body of the animal, which being weaker than the light of the day, but ſtronger than the light of the night, is viſible in the night, but not in the day. The *light* of other bodies which ſhine in the dark is inherent in thoſe

bodies,

bodies, as in putrifying veal, fiſh, rotten wood, phoſphorus, the glow-worm, &c. concerning the laſt of theſe, the eminent anatomiſt and philoſopher, T. Bartholine, has the following obſervation. If a glow-worm be examined, it will appear to have a lucid liquor in the hinder part of it's body, where the heart is placed, by which the heart is moved and illuminated; and this fluid retains it's light, ſo long as the heart of the inſect retains it's life and motion.

Dr. Prieſtley, in his "Heads of Lectures on a courſe of experimental Philoſophy," has given ſo excellent and compendious a view of the principal experiments, that have been made by Valli and others to determine the electricity of animals, that I cannot do better than lay it before you; which I the more readily do, as it will ſave us from the diſguſting detail of a variety of cruel experiments, experiments that I hope you will never be induced to repeat. One alone will ſuffice to give you an idea of the nature of theſe operations.

Mr. Valli opened the abdomen of a frog, in order to lay bare the ſpine of the back, and diſcover the crural nerves which iſſue from it; a few lines above this point, he cut the animal in two, and paſſing his ſciſſars immediately under the origin of theſe nerves, removed the remaining portion of the vertebral column, ſo as only to leave the vertebral which united the bundle of nerves; this portion of the vertebræ was enveloped with a piece of ſheet-lead; the coated part was touched with one end of a metallic conductor, and with the other the ſurface of the thighs which were previouſly ſtripped of their ſkins. The movements produced thereby, were violent, and continued for a long time.

Having thus explained to you the manner in which the animal is prepared for theſe experiments,

ments, I ſhall proceed to point out the principal reſults, as furniſhed by Dr. Prieſtley.

The nerve of the limb of an animal being laid bare, and ſurrounded with a piece of ſheet-lead, or of tin-foil, if a communication be formed between the nerve thus armed and any of the neighbouring muſcles, by means of a piece of zinc, ſtrong contractions will be produced in the limb.

If a portion of the nerve, which has been laid bare, be armed as above, contractions will be produced as powerfully, by forming the communication between the armed and bare part of the nerve, as between the armed part and muſcle.

A ſimilar effect is produced by arming a nerve, and ſimply touching the armed part of the nerve with the metallic conductor.

Contractions will take place if a muſcle be armed, and a communication be formed by means of the conductor between it and a neighbouring nerve; the ſame effect will be produced if the communication be formed between the armed muſcle and another muſcle, which is contiguous to it.

Contractions may be produced in the limb of an animal, by bringing the pieces of metal into contact with each other at ſome diſtance from the limb, provided the latter make part of a line of communication between the two metallic conductors.

The experiment which proves this is made in the following manner. The amputated limb of an animal being placed upon a table, let the operator hold with one hand the principal nerve, previouſly laid bare, and in the other let him hold a piece of zinc; let a ſmall plate of lead or ſilver be then laid upon the table at ſome diſtance from the limb, and a communication be formed by means of water between the limb and the part of the

the table where the metal is lying. If the operator touch the piece of ſilver with the zinc, contractions will be produced in the limb, the moment that the metals come into contact with each other. The ſame effect will be produced, if the two pieces of metal be previouſly placed in contact, and the operator touch one of them with his finger. This fact was diſcovered by Mr. William Cruikſhank.

Contractions can be produced in the amputated leg of a frog, by putting it into water, and bringing the two metals into contact with each other, at a ſmall diſtance from the limb.

The influence which has paſſed through, and excited contractions in one limb, may be made to paſs through, and excite contractions in another limb. In performing this experiment, it is neceſſary to attend to the following circumſtances; let two amputated limbs of a frog be taken, let one of them be laid upon a table, and it's foot be folded in a piece of ſilver; let a perſon lift up the nerve of this limb with a ſilver probe, and another perſon hold in his hand a piece of zinc, with which he is to touch the ſilver, including the foot; let the perſon holding the zinc in one hand, catch with the other the nerve of the ſecond limb, and he who touches the nerve of the firſt limb, is to hold in his other hand the foot of the ſecond; let the zinc now be applied to the ſilver including the foot of the firſt limb, and contractions will immediately be excited in both limbs.

The heart is the only involuntary muſcle, in which contractions can be excited by theſe experiments; contractions are produced more ſtrongly, the farther the coating is placed from the origin of the nerve.

Animals, which were almoſt dead, have been found to be conſiderably revived by exciting this influence.

influence. When these experiments are repeated upon an animal that has been killed by opium, or by the electric shock, very slight contractions are produced, and no contractions whatever will take place in an animal that has been killed by corrosive sublimate, or that has been starved to death. Zinc appears to be the best exciter when applied to gold, silver, molybdena, steel, or copper; the latter metals, however, excite but feeble contractions when applied to each other; next to zinc, in contact with these metals, tin and lead appear to be the most powerful exciters.

It has been found, that, if a plate of zinc is applied to the upper part of the point of the tongue, and a plate of silver to it's under part, on bringing the two metals into contact with each other, a pungent disagreeable feeling, which it is difficult to describe, is produced in the point of the tongue. And if a plate of zinc is placed between the upper lip and the gums, and a plate of gold applied to the upper or under part of the tongue, on bringing these two metals into contact with each other, the person imagines that he sees a flash of lightning, which, however, a by-stander in a dark room does not perceive; and the person performing the experiment perceives the flash, though he is hood-winked.*

After performing this experiment repeatedly, Dr. Munro constantly felt a pain in his upper jaw, at the place to which the zinc had been applied, which continued for an hour or more; and in one experiment after he had applied a blunt probe of zinc to the septum narium, and repeatedly touched with a crown piece of silver applied to the tongue, and thereby produced the appearance of a flash, several drops of blood fell from

* Munro's Experiments on the Nervous System, p. 25.

from that noſtril; and Dr. Fowler, after making ſuch an experiment on his ears, obſerved a ſimilar effect.

RESEMBLANCE OF THE FLUID PUT IN MOTION BY THE FOREGOING EXPERIMENT, TO THE ELECTRICAL FLUID.*

The fluid ſet in motion by the application of the metals to each other, and to animal bodies, or to water, agrees with or reſembles the electrical fluid in the following reſpects:

Like the electrical fluid, it communicates the ſenſe of pungency to the tongue.

Like the electrical fluid, it is conveyed readily by water, blood, the bodies of animals, the metals; and is arreſted in it's courſe by glaſs, ſealing-wax, &c.

It paſſes, with ſimilar rapidity, through the bodies of animals.

Like the electrical fluid, it excites the activity of the veſſels of a living animal; as the pain it gives, and hemorrhagy it produces, ſeems to prove. Hence, perhaps, it might be employed with advantage in amenorrhœa. It excites convulſions of the muſcles in the ſame manner, and with the ſame effects as electricity.

When the metals and animal are kept ſteadily in contact with each other, the convulſions ceaſe, or an equilibrium ſeems to be produced, as after diſcharging the Leyden phial.

GENERAL OBSERVATIONS.

A view of the great *agents* in nature naturally leads us to conſider the opinion of thoſe who wiſh to

* Munro's Experiments on the Nervous Syſtem, p. 38.

to ſet religion and reaſon in oppoſition to each other, and to ſuppoſe that philoſophy and revelation can never agree. But, in oppoſition to ſuch inſidious attempts, attempts which never were deſigned to enlarge the mind, or to improve the heart, it may eaſily be made to appear, that, take philoſophy in it's moſt improved ſtate, enriched by the diſcoveries of ages, examined by the teſt of the cloſeſt reaſoning, elevated above the fallacies of the ſenſes, and of appearances; and yet, in this improved ſtate, it ſhall be found perfectly to correſpond with the philoſophy of ſcripture, rightly underſtood. The *word* of GOD is as perfect as HIS work. Both proceed from the one fountain of truth, who cannot contradict himſelf. HIS WORD and HIS WORK mutually illuſtrate each other. The one is not to be underſtood without the other. For both are the offsprings of *divine love*, manifeſted in *wiſdom*, and exerciſed in *power*.

Creation may be conſidered as the grand chain of cauſes and effects, intimately connected together. It is the work of omnipotence, guided by infinite wiſdom, and excited to work by communicative goodneſs. But do we not entertain wrong ideas on this important ſubject, if we imagine, that any part of this grand ſyſtem ſtands unconnected? or, as if the *Great Maſter Builder* was obliged to collect diſcordant materials from different parts, and overcoming the repugnance of their natures, to form one whole out of theſe heterogeneous ſubſtances? Whereas, the truth appears to be, that in his divine hand, the one naturally and orderly produces the other; that which was the effect of a prior principle, becomes the cauſe of that which follows it immediately; and again, this effect becomes an inſtrumental cauſe in it's turn; and is thus extended in a long ſeries, until all are completed in outward nature.

Let

Let us examine how this will agree with the Mosaical account of the creation; for, although we may readily allow, that that book contains more interesting and important subjects, than the detail of the mere creation and formation of this material system; yet the natural account, when rightly understood, may be found to be most accurate, philosophical, and just. The great and spiritual truths, conveyed under that form, may yet be delivered down to us in a vehicle of the most accurate philosophical truth; the stricter the truth, the greater and more perfect the analogy and correspondence; but it seems to have been the peculiar fate of these sublime and ancient writings of the Hebrew sage, that they have been supposed to contain what they did not, whilst their real and most important contents have been greatly overlooked. The ideas of the Divine Mind disclosed, the energies of his almighty will exerted, produced *motion* in different degrees, as the instrumental cause for future productions. Hence the motion of spirits, of minds, of life, of thought, of light, of the heavenly bodies, of blood, and of the sap. Hence this motion, dependent and continued from the one source of life and motion, may be considered as the key of natural knowledge, which opens the temple of physical truth. Motion is the visible discovery of the divine hand; motion is the grand connecting link between the spiritual and natural worlds; by this the energies of the one are impressed on the other.

This motion, proceeding from a pure and superior system, was at first most perfect and full, unencumbered by matter, unimpeded by obstructions.

Now, in the first *day*, (or in the first state of creating things; for as yet there was no sun and earth, and therefore no measure of day and night;) in

in this firſt ſtate of things, the ſcripture ſays, LIGHT was formed, or rather the matter of light, by the means of pure original motion. Now *the matter* of light is elementary *fire*. This is evident from the moſt intimate relation between fire and light; light being only an effect, an outward viſible manifeſtation of latent fire.

This pure elementary *fire*, the matter or ſubſtance of light, produces that rapid *motion* of light from the ſun or ſtars to the earth, travelling with ſuch amazing velocity. *Fire* and *light* combined, produced air, or the firſt and pureſt etherial particles; and, therefore, in the Moſaical account, the firmament, the expanſe, or the atmoſphere of the AIR, was the *ſecond* day's work, or the *ſecond* ſtate of things in their progreſs to perfection and fulneſs. This elementary principle is not ſo ſubtil and active as it's parents, fire and light; yet it is more ſubtil and active than *vapour* or *water*; therefore it holds the intermediate rank between theſe, and is a connecting link in the great chain, as it is produced by *fire* and *light*; ſo again, when partly deprived of theſe, it is the inſtrumental cauſe to form the vapours and water.

That *fire* and *light* produce AIR, may be illuſtrated by various experiments; the reſpiration of plants, and the purity of the air, which they produce, when expoſed to the agency of *light*; and the great quantities of different airs produced in various chemical experiments by the activity of *fire*.

Air condenſed, expoſed to obſtructions, and thus deprived of the greateſt portion of it's etherial fire, becomes firſt *vapour*; and as the fire diſſipates, and the motion ceaſes, it becomes WATER in the various forms of *miſt*, *dew*, *rain*, &c. In this ſtate, it is almoſt entirely deprived of it's original motion; is leſs ſubtil, and more groſs; is become an object of the outward ſenſes, and is ſubject to the laws of gravitation.

Water

Water is the great ſupport of animal and vegetable ſubſtances, which at length are reduced to earth in their various changes, from the firſt principles of active nature, down to the loweſt, groſſeſt material form ; from the fountain of life, from the architypal ideas of the Divine Mind, through ſpirits to fire, light, ether, air, water, earth, down to ſluggiſh inert matter.

Fire, *light*, *air*, and *water*, may then be conſidered as the grand agents in nature. The earth is, as it were, a baſis for them to reſt and to work upon. In theſe, the circulation of motion in it's deſcent and degrees is preſerved, and the earth is a nidus where they reſt, and where their effects are manifeſted. Thus was there a regular and beautiful deſcent from the ſpiritual to the natural world, from motion to reſt. The wondrous fabric of the earth was not built of diſcordant materials, of jarring elements, forcibly reſtrained by the divine hand continually checking them; but the homogeneous ſubſtance aroſe in a wiſe and orderly ſeries. Each part being preparatory for that which was to ſucceed; every thing being a link in the great chain of order and uſefulneſs; an inſtrumental cauſe to produce the ſucceeding effect, until all was finiſhed and complete, nature ſtood perfect in outward matter: creation was no longer all fire, light, air, or water; but each retained it's reſpective rank; and the groſs material world was produced, able to ſuſtain minerals, plants, animals, and man.

Thus did the DIVINE ARCHITECT accompliſh this great and ſtupendous work, by the moſt ſimple means; by a regular deſcent from the ſpiritual to the natural world; a continued ſeries proceeding from the higheſt to the loweſt, from the pureſt motion to inactivity, from the higheſt principles of intelligent mind, down to the loweſt, groſſeſt,

heavieſt matter. Thus were all things ordered in infinite wiſdom: cauſes were employed, moſt ſimple and prolific, to accompliſh the end deſigned. Creation was accompliſhed: the earth ſtood complete: the work of divine power reſulting from *divine wiſdom* and *mercy*. It was made the theatre of his *goodneſs*; on which he might diſplay it, and communicate it to his various creatures, who thus might rejoice in their exiſtence; and manifeſt his praiſe, by enjoying happineſs, and riſing in perfection through endleſs ages.

Thus was the *earth* deſigned to be the repoſitory of the human race, the ſeminary of men; until, full of years and wiſdom, they were ripe for a happier change; were prepared to quit the periſhing body, and to be tranſplanted into a paradiſe of endleſs delights.

The whole material ſyſtem was alſo a volume of divine inſtruction opened to man, in which he might read and underſtand, and live for ever; in which he might diſcover immenſe benevolence, deſign, and order; and thus be led to underſtand, and to adore him who is the ſource all things.

LECTURE

LECTURE L.

On Magnetism.*

THOUGH the phenomena of the magnet have for many ages engaged the attention of natural philosophers, both from their singularity and importance; we are not yet in possession of any hypothesis, that will satisfactorily account for the various properties of the magnet, or point out those links of the chain, that connect it with the other phenomena of the universe.

It is known by the works of Plato and Aristotle, that the ancients were acquainted with the attractive and repulsive powers of the magnet; but it does not appear, that they knew of it's pointing to the pole, or the use of the compass. That property of the magnet, whereby, when properly suspended, it turns towards the north pole, renders it of the utmost service to mankind in general, but more particularly to an Englishman; the riches and power of whose country depend on navigation.

The powers of the magnet excited the wonder of the ancients; they were to them inexplicable, and remain so. Posterity, instead of being able to remove the difficulties, have only by their researches, found out new wonders equally inexplicable. All, therefore, that I shall be able to do, will be to relate to you the principal qualities of this curious phenomenon. "The magnet is a proof, that nature has many secrets, and that philosophy, if contented with present knowledge, forgoes most valuable and interesting discoveries, towards

* See my Essay on Magnetism.

towards which, perhaps, the previous ſteps are already trodden." From it's action on the compaſs in all parts of the world, it is plain, that it's influence is univerſal. From our knowledge of this, we are naturally led to ſuppoſe, that there may be other *inviſible agents* exerting their influence on us, and on our globe.

Let the modern philoſopher,* who denies the exiſtence of a God, becauſe he cannot perceive him with his corporeal eyes, tell you *what magnetiſm* is, and *how* it exiſts. Let him, who will underſtand every thing that exiſts, before he allows of it's exiſtence, firſt employ himſelf here; and when he has given the world a proof of his powers, let him attempt an higher ſubject.

The loadſtone, leading-ſtone, or natural magnet, is an iron ore or ferruginous ſtone, found in the bowels of the earth, generally in iron mines, of all forms and ſizes, and of various colours. It is endowed with the property of attracting iron; and of both pointing itſelf, and alſo enabling a needle, touched upon it, and duly poiſed, to point towards the poles of the world.

Loadſtones are in general very hard and brittle, and for the moſt part more vigorous in proportion to their degree of hardneſs. Conſiderable portions of iron may be extracted from them. Newman ſays, that they are almoſt totally ſoluble in ſpirit of nitre, and partially in the vitriolic and marine acids.

Mr. Kirwan ſays, that the magnet ſeems to contain a ſmall quantity of ſulphur, is often contaminated with a mixture of quartz and argill; it is poſſible, it may contain nickel, for this, when purified to a certain degree, acquires the proper-ties

* Condorcet and many of his ſchool, have laughed at mankind for believing in an inviſible Being.

ties of a magnet; but it's conſtitution has not as yet been properly examined.*

Artificial magnets, which are made of ſteel, are now generally uſed in preference to the natural magnet; not only as they may be procured with greater eaſe, but becauſe they are far ſuperior to the natural magnet in ſtrength, and communicate the magnetic virtue more powerfully, and may be varied in their form more eaſily, ſo that the natural magnet is now very little eſteemed, except as a curioſity.

The power of attracting iron, &c. poſſeſſed by the loadſtone, which is alſo communicable to iron and ſteel, is called MAGNETISM. It has been ſuppoſed, that iron and the loadſtone were the only two bodies which could be rendered magnetical; but it now appears, that nickel, when purified from iron, becomes more inſtead of leſs magnetic, and acquires, what iron does not, the properties of a magnet.†

A rod or bar, of iron or ſteel, to which a permanent polarity has been communicated, is called a *magnet*.

The points in a magnet which ſeem to poſſeſs the greateſt power, or in which the virtue ſeems to be concentrated, are termed *the poles of a magnet*.

The magnetical meridian is a vertical circle in the heavens, which interſects the horizon in the points to which the magnetical needle, when at reſt, is directed.

The axis of a magnet is a right line, which paſſes from one pole to the other.

The equator of a magnet is a line perpendicular to the axis of the magnet, and exactly between the two poles.

 The

* Kirwan's Elements of Mineralogy, p. 27[illegible].
† Ibid. p. 369.

The diſtinguiſhing and characteriſtic properties of a magnet, are,

Firſt, It's attractive and repulſive powers.

Secondly, The force by which it places itſelf, when ſuſpended freely, in a certain direction towards the poles of the earth.

Thirdly, It's dip or inclination towards a point below the horizon.

Fourthly, The property which it poſſeſſes of communicating the foregoing powers to iron or ſteel.

OF THE TENDENCY OF IRON AND A MAGNET TO APPROACH EACH OTHER.

This curious property of the magnet was that by which it was firſt diſcovered, and by which it engaged the attention of the curious.

Every ſubſtance that contains iron, is more or leſs attracted by the magnet. And ſo univerſally is this metal diſſeminated, that there are very few ſubſtances that are not in ſome degree capable of being attracted by the magnet. You will find it in animals, vegetables, minerals, and even in the air.*

Iron is attracted with different degrees of force, according to the different ſtates of it's exiſtence; but it never becomes quite inſenſible to the magnetic power. Even the pureſt calx, or the completeſt ſolution ever made of the metal, when accurately examined, is found to be in ſome degree obedient to the magnet.

TO ASCERTAIN WHETHER A BODY HAS ANY IRON, OR IS CAPABLE OF BEING ATTRACTED BY THE MAGNET.

If the given body contains evidently a large quantity of iron, on bringing a magnet in contact

* Cavallo on Magnetiſm, p. 66.

tact therewith, you will find them adhere so strongly as to require a certain degree of force to separate them. If the body be not sensibly attracted by the magnet in this way, then you may float it by a piece of wood or cork on water; in this situation it is more easily acted on, and consequently small quantities of iron are readily discovered. The magnet should be presented sideways to the body, and when it is at rest, it is sometimes necessary to bring the magnet within one tenth of an inch distance from the swimming body in order to perceive the attraction.

A still smaller degree of attraction may be discovered by placing the given body upon quicksilver, and then presenting a magnet to it. The vessel, in which the quicksilver is contained, should be at least six inches in diameter, otherwise the curvature of the fluid will be perpetually carrying the body towards the sides of the vessel. The quicksilver should be pure, and occasionally cleared by passing it through a funnel of clean writing paper; the smaller the aperture of the funnel, the better it will answer the purpose. The air should be agitated as little as possible. Attending to these precautions, you will seldom fail to discover whether a body contains any ferruginous particles.

I place a piece of iron on a cork, and put the cork into a bason of water. I present a magnet to it, and it is attracted thereby, and follows the magnet, so that I can move it without touching, wherever I please. On this principle, many ingenious and entertaining pieces of mechanism have been contrived.

The tendency between the magnet and the iron is reciprocal; for, if the magnet be put on the cork, it will follow the iron in the same manner, as this followed the magnet. And this attraction takes place, although a piece of paper, glass,

brafs, &c. be interpofed between the magnet and the iron.

The reciprocal tendency of iron to a magnet, and of a magnet to iron, is pleafingly illuftrated by fufpending a magnet under the fcale of a ballance, and counterpoifing it by weights in the other fcale; when thus counterpoifed, bring a piece of iron towards it, and the magnet will immediately defcend. Reverfe the experiment, by fufpending the iron from the fcale, and the iron will now defcend and follow the magnet.

I place a magnet upon a ftand, to raife it fome diftance from the table; I fhall bring a fmall fewing needle towards it, keeping the thread which is in the needle in my hand, to prevent the needle from fixing itfelf to the magnet; and the needle endeavouring on one hand to fly to the magnet, and being withheld on the other by the thread, remains pleafingly fufpended in the air.

Mathematicians have endeavoured to compute the force with which the magnetic attraction acts at different diftances, but hitherto without fuccefs. No law has been afcertained, upon which any dependance can be placed.

Though many experiments have been made to difcover, whether the force by which two magnets are repelled or attracted, acts only to a certain diftance; whether the degrees of it's action within, and at this diftance, is uniform or variable, and in what proportion, to the diftances it increafes or diminifhes; yet we can only infer from them, that the magnetic power extends further at fome times, than it does at others, and that the fphere of it's action is variable.

The fmaller the loadftone or the magnet is, the greater is it's force, *cæteris paribus*, in proportion to it's fize. When the axis of a magnet is fhort, and of courfe it's poles very near, their action

action on each other weakens the magnetic force. A variety of other caufes will alfo occafion great irregularity in the attraction of magnetifm. The attraction is, as I fhall fhew you, always ftrongeft at the poles of the magnet; and moft fo when the body is near the magnet, but diminifhes, as either recedes from the other. It appears alfo from experiment, that a magnet attracts another magnet with lefs force, than it does a piece of iron.

Of the Poles of a Magnet.

It has been already obferved to you, that there are certain points of a magnet called the *poles*, which are poffeffed of the greateft magnetic force, and in which it's virtues feem as it were to be concentrated. This I fhall prove by an eafy experiment: here is a parcel of fmall iron balls; I fhall try what number of thefe the magnetic bar will fuftain at different places, and you find that it fupports the greateft number near the ends; this will anfwer our purpofe in the firft inftance; you will find this further confirmed by the fubfequent experiments, defigned to *point out*, with accuracy, *the fituation of the poles of a magnet.*

I have covered a pane of glafs with writing paper, that the difference in colour may enable us to difcern more diftinctly what effect a magnet has on fteel filings ftrewed over the paper; I place this pane over a magnet, fift fome fteel filings thereon; thefe you fee arrange themfelves in a very curious manner; thofe points from which the curves feem to rife, and over which the filings ftand in an erect pofition, are the poles of the magnet.

Here is a fmall needle inclofed in a glafs ball; move this over a magnetic bar, and the needle will be

be perpendicular to the bar, when it is over either of the poles.

The poles of a magnet may be aſcertained with great accuracy by means of a ſmall dipping needle (*fig.* 7, *pl.* 2, *Electricity*); place this on a magnet, and move it backwards and forwards till the needle is perpendicular to the magnet, it will then point directly to one of the poles. When it is between the north and ſouth poles, ſo that their mutual actions ballance each other, the center of the needle will ſtand over what is called the equator of the magnet, and the needle will be exactly *parallel* to the bar; between this ſituation and the poles, it inclines to the bar in different angles, according to it's diſtance from the poles.

OF THE ACTION OF THE MAGNETIC POLES ON EACH OTHER.

In the action of the magnetic virtue, at the poles, there is a ſtrong ſimilarity with that of electricity; thus the contrary, or north and ſouth poles of two magnets *attract* each other, but poles of the *ſame name*, as two north or two ſouth poles, *repel* each other.

Suſpend on a point a touched needle, then preſent towards it's north pole the ſouth pole of a magnet, and it will be attracted by, and fly towards it; preſent the other pole of the magnet, and the needle will fly from it.

Strew a few ſteel filings upon a pane of glaſs, put either the north or ſouth pole of one of the bars under the pane; the filings will riſe upon the glaſs as the magnet approaches. Bring the ſame pole of the other bar directly over that under the glaſs, and when it is at a proper diſtance, the ſteel filings will drop flat on the pane.

Fix

Fix two needles horizontally in two pieces of cork, and put them in water; if the poles of the ſame name are placed together, they will mutually repel each other. If the poles of a contrary denomination are turned towards each other, they will be attracted and join.

Dip the north or ſouth ends of two magnets in ſteel filings, which will hang in cluſters from the end of the bars; bring the ends of the bars towards each other, and the ſteel filings on one bar, will recede from thoſe on the other. Dip the ſouth pole of one magnet, and the north pole of the other, into ſteel filings, and bring the ends near to each other, and the tufts of filings will unite, forming ſmall circular arches.

THE ACTION OF THE MAGNETIC POLES RENDERED VISIBLE BY STEEL FILINGS.

I place the glaſs pane covered with paper over a magnetical bar, and ſtrew it over with ſteel filings; on ſtriking the glaſs gently, the filings diſpoſe themſelves in ſuch manner, as to repreſent with exactneſs the courſe of the magnetic matter. The curves, by which it ſeems to go from pole to pole, are pleaſingly indicated by the arrangement of the filings; the largeſt curves riſe from one polar ſurface, and extend to the other; they are larger in proportion as they riſe nearer the axis or center of the polar ſurface; the interior curves are ſmaller and ſmaller in proportion to their diſtance from the end, ſee *fig.* 8, *pl.* 2. The greater the diſtance between the poles of a magnet, the larger are the curves which ariſe from the polar ſurface.

Let two magnets be placed in a ſtrait line at a ſmall diſtance from each other, the ſouth pole of the one oppoſed to the north of the other; lay a pane of glaſs over them, ſprinkle it with ſteel filings,

filings, and then ſtrike the pane gently with a key, and the filings will arrange themſelves in the direction of the magnetic virtue; thoſe that lie between the two polar ſurfaces, and near the common axis, are diſpoſed in ſtrait lines, going from the north pole of one, to the ſouth pole of the other, as if uniting and joining together, *fig.* 9, *pl.* 2.

Place two north or two ſouth poles under a pane of glaſs, on which iron filings have been ſtrewed, andthe filings will be diſpoſed into curves, which ſeem to turn back and avoid each other, *fig.* 10, *pl.* 2.

In magnetiſm, as well as in electricity, it is not the mere matter that is attracted, but the ſtate of the magnetic fluid therein, ſo that *the body always becomes magnetic before it is attracted;* and hence there is *no magnetic attraction,* but between *the contrary poles of two magnets.*

When a piece of iron, or any other ſubſtance that contains iron, is brought within a certain diſtance of a magnet, the powers thereof are ſeparated, and *it becomes itſelf a magnet,* having poles, attractive power, and every property of a real magnet. That part which is neareſt the magnet has a *contrary polarity.*

The magnetiſm that *ſoft iron* acquires, when placed within the influence of a magnet, only laſts while it continues in that ſituation, but diſappears as ſoon as it is removed. But with *hard iron,* and particularly with *ſteel,* the caſe is quite different. For the harder the iron, or the ſteel, the more *permanent* is the magnetiſm it acquires; but it is alſo more difficult to render it magnetic.

Thus, if two pieces, one of ſoft iron, the other of hard ſteel, but both of the ſame ſhape and ſize, be brought within the influence of a magnet, and at the ſame diſtance, you will find the iron appear more magnetical than the ſteel; but when the

magnet

magnet is removed, the ſoft iron inſtantly loſes it's magnetiſm, whereas the ſteel will preſerve it for a long time.

A magnet will therefore attract ſoft iron more forcibly than hard iron, becauſe it can render it more ſtrongly magnetical.

In the foregoing experiments, the ſteel filings became ſo many little magnets, with contrary poles. On the ſame principles, a large key, or any other untouched piece of iron, will *attract* and ſupport a ſmall piece of iron, while it is near the pole of a magnet, but will let it fall when removed therefrom.

A ball of ſoft iron in contact with a magnet, will attract a ſecond ball, and that a third, till the influence becomes too weak to ſupport a greater weight.

Here is a ſmall whirligig, *fig.* 11, *pl.* 2, with an iron axis; I ſpin the whirligig, and then take it up by a magnet, and you will not only find that it will continue ſpinning longer than if it were left to whirl on the table, but a ſecond and third whirligig may be ſuſpended one under another, and yet continue in motion. The number ſuſpended depends on the ſtrength of the magnet.

Of Magnetic Centers.

There is a point between the two poles, where the magnet has *no attraction nor repulſion*; this point is called the *magnetic center*, though it is not always exactly between the two poles.

Paſs the dipping needle, *fig.* 7, *pl.* 2, over a mganetic bar, and you will find a place between the two poles, where the needle will be parallel to the bar but if you remove it ever ſo little from thence, it immediately inclines towards the poles, and

when

when over either pole, is perpendicular to the bar.

This effect is alſo pleaſingly exhibited, by ſurrounding a magnet with ſmall compaſs needles. I place the needles on theſe braſs ſtands, ſo that they may be nearly in the ſame place with the bar, and you ſee thoſe near the ends incline towards the pole, but that the two needles near the middle of the bar are parallel thereto, not inclining to either pole, ſee *fig.* 12, *pl.* 2. You may alſo obſerve, that the north pole of the magnet attracts the ſouth poles of all the needles, and the ſouth, the north of the needles.

Lay a number of magnetic bars in a ſtrait line with the north and ſouth poles together, paſs the dipping needle over them, and you will find a magnetic center at each place of contact, the union of the two powers deſtroying their action; ſeparate them, and you have the north and ſouth poles as at firſt.

Upon the ſame principles, if a magnetic bar be broken into any two parts, *each part becomes a magnet*, having two poles; the ends of each, next to where it was broken acquiring a polarity contrary to the other end. Place a magnetic needle upon one of the ſtands, and when the needle is ſteady, place an iron bar of about eight inches long, and between a quarter of an inch and one inch thick, upon the ſtand, ſo that one end of it may be on one ſide of the north pole of the needle, and ſo near it as to draw it a little way out of it's natural direction. In this ſituation, approach gradually the north pole of a magnet, to the other extremity of the bar, and you will ſee that the needle's north end will recede from the bar more and more, in proportion as the magnet is brought nearer to the bar. If the experiment be repeated, with only this difference, viz. that the ſouth pole

of the magnet be directed towards the iron bar, then the north end of the needle will advance nearer and nearer to the bar, in proportion as the south extremity of the magnet is brought nearer to the iron.

The reason of this phenomenon is, that, by the approach of the north pole of the magnet, in the first case, the extremity of the iron bar, which lies next to it, acquires a south polarity, and of course the opposite extremity acquires the north polarity; in consequence of which, the needle is repelled, because magnetic poles of the same name repel each other; but in the second case, when the south pole of the magnet is brought near the bar, the end of the bar, which is next to it, acquires the north polarity, and the opposite end acquiring the south polarity, attracts the north end of the needle.

If, whilst the pole of the magnet stands contiguous to one end of the bar, a small magnetic needle be presented within a certain distance to various parts of the surface of the latter, it will be observed, by the attraction and repulsion of the needle, that that half of the bar which is next to the magnet, possesses the contrary polarity, and the other half the same polarity with the pole of the magnet that is applied to the iron.

The magnetic center, however, or the limit between the polarities, is not always in the middle of the bar; it is generally nearer that end which is presented to the magnet. This difference is greater as the magnet is weaker, and the length of the bar increases; but when the bar exceeds a certain length, which depends on the strength of the magnet, then the bar acquires several successive poles, viz. when the north pole of the magnet is contiguous to one of it's extremities, that extremity becomes

comes a ſouth pole ; a few inches farther on you will have a north polarity, then another ſouth polarity, and ſo on. In this caſe, the firſt magnetic center comes very near that end of the bar which ſtands next to the magnet, and other magnetic centers are formed between every pair of ſucceſſive poles.

Thoſe ſucceſſive poles become weaker and weaker in power, according as they recede from that end of the bar which is contiguous to the magnet; ſo that in a pretty extended bar, they quite vaniſh long before they come to the farther end of it; hence, if one pole of a magnet be applied to the end of a long bar, the other end of the bar will not thereby acquire any magnetiſm. This will happen, when a magnet, capable of lifting about two pounds weight of iron, is applied to one extremity of an iron bar, about one inch ſquare, and about five feet long. On removing the magnet, the bar, if of ſoft iron, will immediately loſe all it's magnetiſm ; otherwiſe will retain it a longer or ſhorter time, in proportion to it's hardneſs.

TO RENDER IRON AND STEEL MAGNETIC.

The communication of the magnetic power to iron and ſteel bars, is termed by artiſts *touching a needle*, a *bar*, &c. To give a detail of the various proceſſes, uſed by different artiſts, for communicating magnetiſm to iron, would take up too much of our time; I ſhall therefore only mention two methods, which you will find adequate to every common purpoſe.

I firſt place two magnets,*A,B, *fig*.13, *pl*.2, in a ſtrait

* The longer and ſtronger theſe are, the better they will anſwer the purpoſe.

ſtrait line, the north end of one oppoſed to the ſouth end of the other, but at ſuch a diſtance that the bar to be touched may reſt upon them, taking care that the end I deſigned for the ſouth, be laid upon the north end of one bar, and the north end on the ſouth pole of the other bar.

I now take two other bars, D and E, and apply the north end of D, and the ſouth end of E, to the middle of the untouched bar C, elevating their other ends ſo as to form an acute angle with the ſaid bar. I now ſeparate D and E, drawing them different ways along the ſurface of the bar C, but preſerving the ſame elevation all the way; I remove D and E to the diſtance of a foot or more from the untouched bar C, and bringing the north and ſouth ends in contact, I apply them again to the middle of the bar C, and ſhall repeat the proceſs three or four times; after which I ſhall touch the other three ſurfaces in the ſame manner, and the bar will thereby have acquired a ſtrong and permanent magnetiſm. This was one of the methods uſed by *Dr. Knight*, who firſt taught us the great advantage that might be obtained from the uſe of magnetic bars, giving by their means a magnetiſm to compaſs needles double in force to that which the ſtrongeſt *natural loadſtone could communicate*. He was the firſt alſo who found the way of working on the natural magnet, ſo as to increaſe it's power in a great degree, and of inverting it's poles at pleaſure.

You may readily communicate the virtue to untouched bars by a horſe-ſhoe magnet,* either ſingle or compound; the bar to be touched ſhould be laid on two other magnets, as in the preceding caſe; the horſe-ſhoe magnet muſt be placed on the middle of the untouched bar, with the north end towards that you deſigned to be the ſouth;

 you

* Fig. 15, pl. 2, repreſents a horſe-ſhoe magnet.

you are then to draw it backwards and forwards over the bar five or six times, but be careful when you remove it that it is at that time over the middle of the bar. The ſame operation is to be uſed with the other ſurfaces of the bar.

A ſmall compaſs needle may be touched, by being put between the oppoſite poles of two magnetic bars; while it is receiving the magnetiſm, it will be violently agitated, moving backwards and forwards as if it were animated; when it has received as much magnetiſm as it can acquire in this way, it becomes quieſcent.

TO TOUCH A HORSE-SHOE MAGNET.

Place a pair of magnetic bars againſt the ends of the horſe-ſhoe magnet, with the ſouth end of the bar againſt that end of the horſe-ſhoe, which is intended to be the north; and the north end of the other bar to that which is to be the ſouth: the contact or lifter of ſoft iron to be placed at the other end of the bars. In this ſituation the magnetic fluid which circulates through the bars will endeavour to force a paſſage through the horſe-ſhoe magnet, and thus facilitate the further communication of the magnetic virtue to the horſe-ſhoe magnet: to this end, rub the ſurfaces of the horſe-ſhoe with a pair of bars placed in the form of a compaſs, or with another horſe-ſhoe magnet, turning the poles properly towards the poles of the horſe-ſhoe magnet, being careful that theſe bars never touch the ends of the ſtrait bars, as this would diſturb the current of the magnetic fluid, and injure the operation. If the bars are ſeparated ſuddenly from the horſe-ſhoe magnet, it's force will be conſiderably diminiſhed; to prevent this, ſlip on the lifter or ſupport to the end of the horſe-ſhoe magnet, but in ſuch a manner, however, that it may not touch the bars;

the

the bars may then be taken away, the ſupport ſlid to it's place, and left there to ſtrengthen the circulation of the fluid.

TO MAKE A MAGNETICAL BAR WITH SEVERAL POLES.

Place magnets at thoſe parts where the poles are intended to be, the poles to be of a contrary name to thoſe required; and if a ſouth pole is fixed on one part, the two next places muſt have north poles ſet againſt them; conſider each piece between the ſupporters as a ſeparate magnet, and touch it accordingly.

The difference in the nature of ſteel with reſpect to receiving magnetiſm, is exceeding great, as is eaſily proved by touching in the ſame manner, and with the ſame bars, two pieces of ſteel of equal ſize, but of different kinds. With ſome ſort of ſteel a few ſtrokes are ſufficient to impart to them all the power they are capable of retaining; other ſorts require a longer operation; ſometimes it is impoſſible to give them more than a juſt ſenſible degree of magnetiſm.

Steel, that is hardened, receives a more perfect magnetiſm than ſoft ſteel, though it does not appear that they differ from each other in any thing but the arrangement of the parts; perhaps the ſoft ſteel contains phlogiſton in it's largeſt pores, while hardened ſteel contains it in the ſmaller. Iron and ſteel have very little air incorporated in their pores; when they are ſeparated from the ore, they are expoſed to a moſt intenſe degree of heat; and moſt of the changes to which they are afterwards ſubmitted, are effected in a red-hot ſtate. A piece of ſpring-tempered ſteel will not retain as much magnetiſm as hard ſteel, ſoft ſteel ſtill leſs, and iron ſcarce retains any. From ſome experiments of Mr. Muſſchenbroek, it appears, that when iron is

united with an acid, it will not become magnetical; but if the acid be ſeparated, and the phlogiſton reſtored, it will become as magnetical as ever.

In communicating magnetiſm, it is beſt to uſe weak magnets firſt, and thoſe that are ſtronger afterwards; but you muſt be very careful not to uſe weak after ſtrong magnets.

A magnet can never communicate a greater power than itſelf poſſeſſes, or even of an equal degree; but as ſeveral magnets of nearly an equal degree of magnetiſm, by being joined together, have a ſtronger power than either of them ſingly; in order to impart a ſtronger magnetic power to a given body A, by means of a weak magnet B, you muſt firſt render ſeveral bodies C, D, E, F, &c. weakly magnetic, and then by properly joining C, D, E, F, together, you may communicate to another body, or ſeveral bodies, a ſtronger magnetiſm, and thus by degrees be able to communicate to A, the deſired degree of magnetic power.

A magnet loſes nothing of it's own power by communicating magnetiſm to other ſubſtances, but is rather improved thereby.

If bars of iron are *heated*, and then cooled equally, in various directions, as parallel, perpendicular, or inclined to the dipping needle, the polarity will be fixed *according to their poſition*, ſtrongeſt when they are parallel to the dipping needle, and ſo leſs by degrees, till they are perpendicular to it, when they will have no fixed polarity; but if, upon cooling a bar of iron in water, the under end is conſiderably hotter than the upper, and the upper end is cooled firſt, it will ſometimes become the north pole, but not always. If iron, or ſteel, undergo a *violent attrition* in any one particular part, it will acquire a polarity; if the iron is ſoft, the magnetiſm remains

mains very little longer than while the heat continues. *Lightning* is the ſtrongeſt power yet known in producing a ſtream of magnetiſm; it will, in an inſtant, render hardened ſteel ſtrongly magnetical, and invert the poles of a magnetic needle.

Every kind of violent percuſſion weakens the power of a magnet. A ſtrong magnet has been entirely deprived of it's virtue by receiving ſeveral ſmart ſtrokes of a hammer; indeed, whatever deranges or diſturbes the internal pores of a magnet, will injure it's magnetic force, as the bending of touched iron, wires, &c.

Fill a ſmall dry glaſs tube with iron filings, preſs them in rather cloſe, and then touch the tube as if it was a ſteel bar, and the tube will attract a light needle, &c.; ſhake the tube ſo that the ſituation of the filings may be diſturbed, and the magnetic virtue will vaniſh.

But though a violent percuſſion will deſtroy a fixed magnetiſm, yet it will give polarity to an iron bar which had none before; for a few ſmart ſtrokes of an hammer, on an iron bar, will give it a polarity, and by hitting firſt one end of the bar, and then the other, while it is held in a vertical ſituation, the poles may be changed. Twiſt a long piece of iron wire backwards and forwards ſeveral times, then break it off at the twiſted part, and the broken end will be magnetical.

The pole of a magnet always produces the contrary polarity on a bar to which it is applied: therefore, if two bars fully touched have the poles of the ſame name joined together, they tend to produce on each other a force of a contrary name to that with which they are endowed; and this effect will diminiſh the polar force of each bar; conſequently the magnetic force of each longitudi-

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nal element of an artificial magnet diminiſhes as it's bulk is increaſed, and the total force of two magnets fully touched, and of the ſame length but unequal in bulk, will be in a leſs ratio than that of their maſs.

If the magnet does not touch the bar, but is held at ſome diſtance from it, the phenomena will be the ſame; but the bar will acquire leſs magnetiſm than when it was in contact with the magnet.

Each point of a magnet may be looked on as the pole of a ſmaller magnet, tending to produce on the points of the magnet a force contrary to it's own. The effect of this tendency will be greater, in proportion to the force of the point, and it's nearneſs to thoſe points on which it acts; and the force of a magnet will depend on the reciprocal action of theſe points on each other.

Hence a narrow bar will in general be more powerful than a broader one; and hence alſo the exterior edges and points of a magnet will have more power than the interior ones of the ſame bar.

Hence alſo magnets ſhould never be left with two north or two ſouth poles together; for when they are thus placed, they diminiſh and deſtroy each other's magnetiſm. Magnetic bars ſhould therefore be always left *with the oppoſite poles laid againſt each other*, or by connecting their oppoſite poles by a bar of iron. The magnetic power is increaſed in a magnet, by letting a piece of iron remain attached to one or both of it's poles. A ſingle magnet ſhould therefore be always thus left.

OF ARMED MAGNETS.

As both magnetic poles together attract a much greater weight than a ſingle one, and as the two

two poles of a magnet are generally in oppoſite parts of it's ſurface, in which ſituation it is almoſt impoſſible to adapt the ſame piece of iron to both at the ſame time; two ſoft pieces of iron are applied to the poles of a loadſtone, ſo as to project on one ſide the magnet; theſe pieces being rendered magnetic, another piece of iron can be conveniently adapted to theſe projections, ſo as to let both poles act at the ſame time. The magnet in this caſe is ſaid to be *armed*, the pieces of iron are called the *armature*, the piece of iron that connects the poles is termed the *lifter*.*

To avoid the expence and trouble of the armature, artificial magnets have been made in the ſhape of an horſe-ſhoe, of which I have already ſpoken.

Gaſſendi invented a peculiar kind of armour, by piercing a loadſtone in the direction of the axis, and placing a cylinder of iron in the hole, which augmented conſiderably the force of the magnet.

Here is a ſtrait magnetic bar, the north pole of which ſupports four ounces. I apply another magnet againſt it, but ſo that the north pole thereof is about half an inch from the pole of the other, and it will now ſuſtain near ſeven ounces.

OF THE MAGNETISM OF THE EARTH.

What has been uſually termed the magnetiſm of the earth, might with more propriety be termed the magnetiſm of the atmoſphere. Even the experiments uſually adduced to prove the magnetiſm of the earth, are full proofs that it is an aerial influence; as you will perceive by the account I am going to give you, of the experiments brought in ſupport of the earth's magnetiſm.

Mr. Savery has adduced ſeveral inſtances to ſhew the force and action of the earth's magnetiſm

* *Fig.* 14, *pl.* 2, repreſents an armed magnet.

iſm; among others, that it will ſupport ſmall pieces of iron. He hung up a bar of iron, about five feet long, by a loop of ſmall cord, at the upper end, and then carefully wiped the lower end, and the point of a nail, that there might be no duſt or moiſture to prevent a good contact; then holding the nail under the bar, with it's point upward, he kept it cloſe to the bar, holding only one finger under it's head for the ſpace of thirty or more ſeconds; then withdrawing his finger gently downwards that the nail might not vibrate; if it fell off, he wiped the point as before, and tried ſome other part of the plane at the bottom of the bar. If the ends are ſimilar, and the bar has no permanent virtue, it is indifferent which end is downwards; if it has an imperfect degree of polarity, one end will anſwer better than the other.

The upper end A, of a long iron rod, which has no fixed polarity, will attract the north end of a magnetic needle; the under end B repels the north end of the needle; invert the iron bar, and the end B, which is now the upper one, will attract the north pole of the needle it repelled before. The caſe is the ſame, if the bar is placed horizontally in the magnetic meridian, the end towards the ſouth will be the north pole.

The explanation of this curious phenomenon is eaſily deduced from the foregoing obſervations; for, ſince in theſe northern parts the earth is poſſeſſed of a ſouth magnetic polarity, the loweſt part of the iron bar, by being neareſt to it, muſt acquire the contrary, namely the north polarity; the other extremity of the bar becoming a ſouth pole.

It follows, likewiſe, (and it is confirmed by actual experiment,) that in the ſouthern parts of the earth, the loweſt part of the bar acquires the ſouth polarity; that on the equator the bar muſt be kept horizontal, in order to let it acquire any magnetiſm from the earth; and that, even in theſe

parts

parts of the earth, the moſt advantageous ſituation of the bar is not the perpendicular, but that a little inclined to the horizon. In ſhort, in every part of the world it muſt be placed in the magnetical line, viz. in the direction of the dipping needle. If the iron bar, inſtead of being kept in the magnetical line, be placed in a direction perpendicular to it, then it will acquire no magnetiſm, becauſe in that ſituation the actions of both poles of the earth upon each extremity of the bar are equal. If, inſtead of the above-mentioned two directions, the bar be placed in any other poſition, then it will acquire more or leſs magnetic power, according as it approaches nearer to the former or to the latter of the ſaid two directions.

Iron bars of windows, which have remained long in a vertical poſition, acquire a fixed polarity. Mr. Lewenhoek mentions an iron croſs, which had acquired a very ſtrong polarity. Mr. Canton propoſed to make artificial magnets without the aſſiſtance of natural ones; but in this he was miſtaken, for his poker and tongs were natural magnets, and had their verticity fixed by being heated and cooled in a vertical poſition; and an iron or ſteel bar, though without a verticity, while it remains in that poſition, exerts a polarity, and is able to communicate a fixed verticity to the ſmall bar, and is therefore for the time a natural magnet. And further, every iron bar, from the largeſt ſize to a ſixpenny nail, will exert this power when treated as above-mentioned. But how this power is raiſed ſo ſoon to a degree greatly exceeding that which communicated it, we do not know; nor is it more eaſy to account for the facility with which the magnetic power is withdrawn by a friction contrary to that which gave it.

OF THE DIRECTIVE PROPERTY OF MAGNETS.

Let an iron rod be exactly ballanced and ſuſ-

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pended on a point, ſo as to revolve in a plane parallel to the horizon; communicate the magnetic virtue to this rod, and the extremity will be always *directed towards the north.*

Here is an untouched magnet. I place it on a point, and you may obſerve that I can make it reſt in any given ſituation; I ſhall communicate the magnetic virtue to it, and you will then find it no longer indifferent as to it's ſituation, but it will fix upon one in preference to any other, one end always *pointing to the north.*

Whenever a magnet can move itſelf freely, as if it be ſuſpended by a fine thread, or if it be made to float on water by means of a piece of cork, or if it be ballanced on a point, provided it be not diſturbed by the vicinity of iron; it will always place itſelf ſo as to direct it's north pole towards the north, and the ſouth pole towards the ſouth.

The directive power of a touched needle is of the greateſt importance to mankind; it enables the mariner to traverſe the ocean, and thus unites the arts, the manufactures, and the knowledge of diſtant countries, together. The ſurveyor, the miner, and the aſtronomer, derive many advantages from this wonderful property.

The *mariner's compaſs* conſiſts of three parts, the box, the card or fly, and the needle.

The card is a circle of ſtiff paper repreſenting the horizon, with the points of the compaſs marked on it; the magnetical needle is fixed to the under ſide of this card; the center of the needle is perforated, and a cap, with a conical agate at it's top, is fixed in this perforation; this cap is hung on a ſteel pin, which is fixed to the bottom of the box, ſo that the card hanging on the pin turns freely round it's center; one of the points being from the property of the needle always directed towards the north pole. The box, which contains the card and needle, is a circular braſs box

box hung within a ſquare wooden one, by two concentric rings called jimbals, ſo fixed by croſs centers to the two boxes, that the inner one ſhall retain an horizontal poſition in all motions of the ſhip. The top of the inner box has a cover of glaſs to prevent the card from being diſturbed by the wind. Before the compaſs was invented, the navigating of ſhips was a tedious and precarious operation, and ſeldom performed out of ſight of land; but this inſtrument enables the mariner to travel over the ſeas almoſt in as direct and true a tract, as the land carrier directs his carriage in a well beaten road.

It has been already obſerved, that the ancients do not ſeem to have been acquainted with the directive power of the magnet. The only thing that ſeems capable of being miſtaken for ſome ſuch knowledge, is what Jamblichus tells us in his life of Pythagoras, *That Pythagoras took from Abaris, the Hyperborean, his golden dart, without which it was impoſſible for him to find his road.* But the authority of the writer, as well as the obſcurity of the paſſage, prevents any concluſion being drawn from it.

Paul the Venetian is ſaid to have introduced the uſe of the compaſs in 1260; but this is ſaid not to have been his own invention, but borrowed from the Chineſe. P. Gaubil ſays, the directive power of the needle was known to the Chineſe as early as the year A. D. 223, under the dynaſty of Haz. But the Abbe Renaudot, in his Diſſertation on the Stone, when the Mahomedans went firſt to China, has adduced ſtrong reaſons to prove, that the Chineſe knew nothing of the mariner's compaſs, till it was introduced there by the Europeans. Vertomanus affirms, that A. D. 1500 he ſaw an Eaſt Indian pilot direct his courſe by a compaſs, framed and faſtened like thoſe uſed in Europe; but this muſt

must be received with some caution, as Mr. Barlow, in 1597, says that in a personal conference with two East Indians he was told by them, that instead of our compass they made use of a magnetical needle of six inches or longer, set upon a pin in a dish of white China earth filled with water; that in the bottom of the dish they had two cross lines, to mark the four principal winds, and that the rest of the divisions were left to the skill of the pilot. But to return to Europe, Mr. Perrault, in his parallel between the ancients and the moderns, has cited some verses of Guyot de Provins, who wrote in 1180, which shew distinctly that the mariner's compass was known in the South of France at that time.

By most writers the invention of the compass is ascribed to Flavio Goin of Analsi in Campanee, who lived about the year 1300; and he is said to be the first that applied it to navigation in the Mediterranean.

Mr. de Lalande informs us, that in "Le trésor de Brunet," a manuscript in the French king's library, there is a passage which proves that the compass was made use of about the year 1260.

Here however it may be observed, that though a magnet, which has only two poles, will always, when freely suspended, place itself in the *magnetic meridian*, or in the same plane with other good magnets; yet when a magnet has more than two poles, these may be so situated that the magnet will not traverse, that is, will have no directive power.

Thus suppose an oblong magnetic needle to have a north polarity equally strong at each end, and a south polarity in the middle; it is plain, that as each has an equal tendency towards the north, neither of them can be directed towards the north in preference to the other; consequently the needle

dle cannot traverſe. Though this caſe very ſeldom occurs, yet there are many others, where a needle, when fixed to a card on which the points of a compaſs are drawn, may occaſion conſiderable errors; this has been clearly proved by Dr. Knight and Capt. Greaves. Mr. R. Walker, of Jamaica, has alſo clearly proved, that the only proper ſhape for magnetic compaſs needles, is that where the line of direction is in the edge of the bar; each end of the bar ſhould be alſo pointed. But it will be needleſs for me to enter into the ſubject, as Mr. Walker means to lay his own ideas before the public, in a work which will contain much other curious matter on this part of magnetiſm.

Of the Variation of the Compass.

Though the north pole of the magnet is, in every part of the world, directed nearly towards the *north*, yet it very *ſeldom points exactly thereto*, and conſequently the ſouth pole of the magnet ſeldom points towards the ſouth. In other words, the magnetic meridian ſeldom coincides with the meridian of the place, but generally *varies* from it ſome degrees eaſtward or weſtward.

This *variation* is different in different places on land as well as at ſea, and is alſo continually varying in the ſame place. For inſtance, the *variation* is not the ſame in London as at Paris, or as at the Cape of Good Hope; and the declination at London, or at any other place, is not the ſame now as it was twenty years ago.

This variation is always reckoned from the north; that is, if the north end of a needle vary to the eaſt of the north, the variation is ſaid to be eaſterly; and if it vary to the weſt, the variation is ſaid to be weſterly.

The uncertainty of the quantity of this variation

riation in different parts of the world, is a great impediment to the perfecting of navigation; and philosophers have earnestly endeavoured to investigate it's cause, and, if possible, to correct the errors it occasions. The research has hitherto been in vain, though I must own, I think the subject is in the hand of a person, who bids fair to dispel much of the darkness with which it has hitherto been surrounded; and from what I have seen of Mr. R. Walker's theory, it appears to me correct and judicious, and needs only to be understood to produce conviction. He has also contrived a compass to ascertain the variation of the needle at sea without calculation.

Though the directive power of the compass was applied to the purposes of navigation in the fourteenth and fifteenth century, it does not appear, that there were any apprehensions during that time of it's pointing otherwise than due north and south.

The *variation of the compass* is said to have been first discovered by Columbus, the latter end of the fifteenth century. But the first person who discovered that it was real, and was the same to all needles in the same place, is generally allowed to be Sebastion Cabot. This was about the year 1497.

After the variation was discovered by Cabot, it was thought, for a long time, to be invariably the same, at the same places, in all ages; but Mr. Gellibrand, about the year 1625, discovered that it was different at different times, in the same place.

From successive observations made afterwards, it appears, that this deviation was not a constant quantity, but that it gradually diminished, and at last about 1657 it was found that the needle pointed due north at London, and has ever since been

been increaſing to the weſtward of the north. So that in any one place the variations have a kind of libratory motion, traverſing through the north to unknown limits eaſtward and weſtward. The preſent variation at London is about 23 $\frac{3}{4}$ degrees.

Dr. Halley ſuppoſed that the earth has within it a large magnetic globe, not fixed within to the external parts, having *four* magnetic poles, two fixed, and two moveable, and by this he has endeavoured to account for the phenomena of the needle. His application of this theory to facts, is in many reſpects inadequate, in all laboured and unnatural. Mr. Euler has ſhewn, that he can with two magnetic poles placed on the ſurface of the earth, account for all the phenomena as well as Dr. Halley with four; but his theory has alſo various imperfections.

The variation of the needle may be illuſtrated by placing ſeveral touched needles round a magnetic bar, ſee *fig.* 12, *pl.* 2. Now if the earth be a great magnet, or if it have only a magnetic atmoſphere, it is clear from this experiment that magnetic needles placed on it's ſurface would have different directions in different places, which is conformable to experience; and the apparent irregularities in the variation of the needle muſt be occaſioned by the ſituation of the magnetic poles of the earth.

If the magnetic poles agreed with thoſe of the earth, there would be no variation, and the magnetic needle would point to the true north and ſouth. If the axis of the magnetic poles paſſed through the center of the earth, it would be eaſy to aſſign the quantity of the variation at every place; but as this is not the caſe, to account regularly for the variation, it is neceſſary to know the exact ſituation of the magnetic poles of the earth, their number, force, and diſtance from the

real

real poles; whether they ſhift their place, and if they move, the quantity of motion every year.

OF THE DIURNAL VARIATION OF THE NEEDLE.

About the year 1722, and 1723, Mr. George Graham made a number of obſervations on the diurnal variations of the magnetic needle. In the year 1750, Mr. Wargentin took notice of the regular diurnal variation of the needle; and alſo of it's being diſturbed at the time of *an aurora borealis*. About the latter end of the year 1756, Mr. Canton began to make obſervations on the variation, and in 1759 communicated ſeveral valuable experiments to the Royal Society.

The obſervations were made by him for 603 days; on 574 out of theſe, the diurnal variation was regular. The abſolute variation of the needle weſtward was increaſing, from about eight or nine o'clock in the morning, till about one or two in the afternoon, when the needle became ſtationary for ſome time; after that the variation weſtward was decreaſing; and the needle came back again to it's former ſituation in the night, or by the next morning.

The diurnal variation is irregular when the needle moves ſlowly eaſtward in the latter part of the morning, or weſtward in the latter part of the afternoon; alſo when it moves much either way after night, or ſuddenly both ways in a ſhort time. Theſe irregularities ſeldom happen more than once or twice in a month, and are always accompanied with an *aurora borealis*. The diurnal variation in the months of June and July, is almoſt double that of January and December.

Mr. Canton ſuppoſes that *the diurnal heat of the ſun acts upon the magnetic* parts of the earth, or rather upon the magnet included in the earth.

But

But Mr. Æpinus has ſhewn that this ſuppoſition is inadmiſſible, becauſe agreeable to the hypotheſis the magnetic nucleus muſt be very profound, and it is well known that the ſolar heat does not penetrate to very great depths; there are caves at no great diſtance from the ſurface of the earth, in which a thermometer remains always at the ſame height. The diurnal heat does not penetrate even theſe, there is therefore no probability of it's effects extending to ſtill greater depths.

OF THE DIP OF THE NEEDLE.

If a needle, which is accurately ballanced and ſuſpended ſo as to turn freely in a vertical plane, be rendered magnetical, *the north pole will be depreſſed, and the ſouth pole elevated above the horizon*: this property is called *the dip of the horizon.* As it is very difficult to ballance a needle accurately, the poles are generally reverſed by a magnet, ſo that it's two ends may dip alternately, and the mean of the two is taken.

This property was diſcovered by Robert Norman, about the year 1576. I ſhall give the account of the diſcovery in his own words.

" Having (ſays he) made many and divers compaſſes, and uſing always to finiſh and end them before I touched the needle, I found continually that after I had touched the yrons with the ſtone, that preſently the north point thereof would bend or decline downwards under the horizon in ſome quantity; inſomuch, that to the flie of the compaſs, which before was made equal, I was ſtill conſtrained to put ſome ſmall piece of wax in the ſouth part thereof, to counterpoiſe this declining, and to make it equal again.

" Which effect having many times paſſed my

hands without any great regard thereunto, as ignorant of any ſuch property in the ſtone, and not before having heard nor read of any ſuch matter; it chanced at length that there came to my hands an inſtrument to be made, with a needle of ſix inches long, which needle after I had poliſhed, cut off at juſt length, and made to ſtand level upon the pin, ſo that nothing reſted but only the touching of it with the ſtone: when I had touched the ſame, preſently the north part thereof declined down in ſuch ſort, that being conſtrained to cut away ſome of that part to make it equal again, in the end I cut it too ſhort, and ſo ſpoiled the needle wherein I had taken ſo much pains.

"Hereby being ſtroken into ſome cholar, I applied myſelf to ſeek further into this effect, and making certain learned and expert men (my friends) acquainted in this matter, they adviſed me to frame ſome inſtrument, to make ſome exact trial, how much the needle touched with the ſtone would decline, or what greateſt angle it would make with the plane of the horizon." Thus far Mr. Norman.

The dip is ſaid to be ſubject to a variation. At this time in London it is about $72\frac{1}{2}$ degrees; from ſome late obſervations it appears to diminiſh about fifteen minutes in four years. The nature of this phenomenon is pleaſingly illuſtrated by carrying a ſmall dipping needle from one end of a magnetic bar to the other; when it ſtands over the ſouth pole, the north end of the needle will be directed perpendicularly to it; as the needle is moved, the dip will grow leſs, and when it comes to the magnetic center it will be parallel to the bar; afterwards the ſouth end will dip, and the needle will ſtand perpendicular to the bar, when it is directly over the north pole.

OF

OF THE INFLUENCE OF THE AURORA BOREALIS ON THE MAGNETIC NEEDLE.

Meſſrs. Wilcke and Van Swinden have clearly proved, that there is a connection between the aurora borealis and the magnetic needle; they have ſhewn it to be ſo evident, ſo general, and ſo conſtant, that no one who examined the affections of the one and the other with attention, could have any doubts on the ſubject. It remained however for Mr. Dalton* to give a complete and ſatisfactory account of this connection, and it is with great pleaſure I take this opportunity of recommending his work to your attentive peruſal.

From various obſervations he has ſhewn,† 1. When the aurora appears to riſe only about 5° 10′ or 15° above the horizon, the needle is very little diſturbed, and often inſenſible. 2. When it riſes up to the zenith, and paſſes it, there never fails to be a conſiderable diſturbance. 3. This diſturbance conſiſts in an irregular oſcillation of the horizontal needle, ſometimes to the eaſtward, then to the weſtward of the mean daily poſition, in ſuch ſort that the greateſt excurſions on each ſide are nearly equal, and amount at Mancheſter to about half a degree on each ſide. 4. When the aurora ceaſes, or ſoon after, the needle returns to it's former ſtation.

From theſe facts alone, ſays Mr. Dalton, independent of other obſervations, we cannot avoid inferring, that there is ſomething magnetic *conſtantly* in the higher regions of the atmoſphere,

 that

* Meteorological Obſervations and Eſſays, by John Dalton, 1793.

† Dalton's Obſervations, p. 183.

that has a ſhare at leaſt in guiding the needle ; and that the fluctuations of the needle, during the *aurora*, are occaſioned by ſome mutations that then take place in this magnetic matter, in the incumbent atmoſphere.

OF THE SIMILARITY BETWEEN ELECTRICITY AND MAGNETISM.

The powers of magnetiſm, like thoſe of electricity, are excited and ſeparated by *friction*. This effect is wonderful in both, but more ſo in magnetiſm, where two powers, naturally attracting each other, remain ſeparated in the ſame ſteel bar for many years, and yet they may be reduced to their natural ſtate by the friction of two other magnets, acting in a contrary order to that by which the poles were originally ſeparated.

Magnetiſm and electricity act powerfully at corners, edges, and points.

Magnetiſm may be communicated to a ſmall ſteel needle, by paſſing the diſcharge of a large electrical battery through it.

The diſcharge of an electrical battery through a ſmall magnetic needle, will ſometimes deſtroy the magnetiſm, and ſometimes invert the poles of the magnet. Similar effects have been produced by lightning.

OF THE THEORY OF MAGNETISM.

Here, as in other parts of natural philoſophy, we muſt content ourſelves with mere conjecture. Of the various hypotheſes that have been formed to account mechanically for the phenomena of magnetiſm, that of *Mr. Prevoſt** is undoubtedly the beſt ;

* Prevoſt De l'Origine des Forces Magnetiques à Genêve, 1788.

beſt; but as it depends on a knowledge of *Mr. Le Sage*'s mechanical ſyſtem of the univerſe, it will be impoſſible for me to lay it before you in a ſatisfactory manner; you muſt therefore be contented with a very imperfect ſketch thereof.

Hypothesis.

There exiſts in and about our globe, a very ſubtil fluid poſſeſſing the following properties.

1. It is expanſive, and conſequently diſcrete.

2. The molecules of this fluid are formed by the union of two kinds of elements, A, B, united by affinity.

3. The elements of the different kinds have a greater tendency to each other, than thoſe of the ſame kind.

4. That excepting the preceding property (n. 3), theſe attractions follow the ſame laws as univerſal gravitation.

5. This fluid has an affinity with the particles of iron, and which probably acts only at contact, or when very nearly in contact. This fluid *is decompoſed by iron*, and ſeldom by any thing elſe.

The foregoing properties of the magnetic fluid may be all mechanically explained on the principles of Mr. Le Sage.

To explain the magnetic phenomena of the earth, it is ſufficient to ſuppoſe that one aliment of the magnetic fluid is furniſhed by nature, in greater abundance in one hemiſphere than the other; or that a ſmall portion thereof be decompoſed by ſome of the cauſes perpetually acting in nature, by which means the terreſtrial globe is maintained in a charged ſtate, having a greater

abundance of one element in one hemiſphere than in the other. This accumulation may principally exiſt in the atmoſphere.

On conſidering that the *aurora borealis*, the *zodiacal light*, *electricity*, and *heat*, all in ſome meaſure affect the magnetic needle, there ſeems ground for ſuppoſing that one or other of the elements of the magnetic fluid is furniſhed by the *ſolar rays*.

When we conſider the extent occupied by the magnetic fluid, we are naturally led to inquire whether it's effluvia courſe inceſſantly over land and ſea, only to turn here and there a mariner's compaſs? Being aſſured that GOD governs by a long ſubordination of ſecond cauſes; that HE not only employs a concurrence of cauſes to produce one effect, but likewiſe produces various effects from one and the ſame cauſe; we may ſafely anſwer, that there are other uſes of the magnetic effluvia, beſides thoſe we diſcern. Here again, as in every other part of philoſophy, we have a further confirmation of the littleneſs of human knowledge, and ſee how much pains GOD has taken, ſo to ſpeak, *to hide pride from man.*

LECTURE

LECTURE LI.

On Meteorology.

THERE is ſcarce any ſubject in which mankind feel themſelves more intereſted, than in the ſtate of the *weather*, that is, in the temperature of the air, the influences of wind, rain, &c. It forms a principal topic of common converſation. By the weather, the traveller endeavours to regulate his journies, and the farmer his operations; by it plenty and famine are diſpenſed, and millions are furniſhed with the neceſſaries of life. It is intimately connected with the health of the human body, and with every part of natural hiſtory, and more particularly with agriculture. You will therefore find this branch of philoſophy peculiarly intereſting; the more ſo as it will lead you to conſider the great operations in nature.

"Here you may ſee and admire the changes in the elements, which preſent us with all that is great and wonderful in nature, and which, with a variety little leſs than infinite, work together for the good of man, and the preſervation of the world."

I have long ſince obſerved to you, how improperly the ſcience of natural philoſophy has been treated by it's moſt zealous advocates, and ableſt profeſſors; it is high time for them, after ſo much labour in vain, to return to the point from whence they ſhould have ſet out, and now begin to conſider the great *agency of the elements.* It is by this *agency*, that all the phenomena we perceive are performed; by it the growth of plants, the life of individuals, are ſupported and preſerved; by it the

planets are maintained in their reſpective ſituations, and made to revolve in their orbits.

"There is no hope in the preſent mode of philoſophiſing, but of ſeeing experiments varied, and facts multiplied; and they may be thus multiplied and varied to eternity without advancing us one ſtep towards a knowledge of the cauſes operating in nature. The indefatigable experimentaliſt may proceed for ever, and flounder like the mole in the duſt he raiſes about himſelf; but by continually heaping up of facts, or making experiments, he will never be able to trace either the nature or deſign of the operations carried on in this ſyſtem of things." For the univerſe is a ſyſtem, in which all the parts are connected and related, and *matter*, as a part of the created world, has *motion*; but he who would underſtand the nature of motion, by conſidering motion abſtractedly, (as is the caſe with many modern philoſophers) is ſtudying motion from that which has no motion belonging to it. There is, as I have before obſerved to you, *no inſulated fact in nature*; they are all ſyſtematic, or mechanical, having a double reference; as effects to their cauſes, and as cauſes to their effects. The material world is an immenſe body, compoſed, like our own, of an infinite number of parts, ſo interwoven together, as to unite in one common center. It is the buſineſs of philoſophers to point out theſe connections, and to explain *why they appear to us ſeparated*, and thus lead us to that principle of *unity* which harmonizes, and connects all the works of *creation*.

But alas, you find the philoſopher continually loſing ſight of the true conſtruction of nature, and endeavouring to build ſyſtems upon *matter independently conſidered*, "upon which he can only raiſe ſuch a world as never did nor can exiſt, being

as empty and absurd, as it is arbitrary." "You find physicians treating *of the nature and causes of diseases*, of blemishes, of preternatural appearances in the body; but wholly indifferent, and altogether inattentive to the proceedings of the *healthy œconomy*: you will find *an hundred* dissertations on *fevers*, for *one* upon *life*. The *action of stimuli*, and the *irritability* of the living fibre, have been the subjects of many ingenious discussions; *the regular and uniform action of the fibre*, but of few. It is the same with philosophy; we have treatises on *light*, as *separated* and *divided* by the prism; on *heat*, as *measured* by the *thermometer*; but none *on that ocean of the* SOLAR FLUID, in which all bodies are as it were immersed; none upon the *various influences of the sun*, upon which the natural life, and the activity of all things in the natural world depend.*

If we look into artificial nature, we shall every where find a want of known *agents*. Hence the variety and changes of opinion with respect to a great number of phenomena that are observed in our laboratories; although we can there multiply and vary the processes, and thus subject our conjectures to experiment; but the phenomena being all on a small scale, we are often but very little struck with circumstances, that may in themselves be very important, and which are daily perceived. We are diffident of the exactness of our measures and weights; we suspect some foreign influence, from the vessels used, from the disparity in substances of the same kind and name, or from some unknown action of the air and vapour; and yet, unless we have learned not to be satisfied with vague conjecture, we seldom attend to the notices which

* Young's Essay on the Powers and Mechanism of Nature.
Jones's Physiological Disquisitions.
Adams's Dissertation on the Barometer, &c.

which reſult from the imperfections and inaccuracies of our theories. But in the *laboratory of the atmoſphere*, all the phenomena are carried on upon a ſcale proportioned to their importance among the operations of nature, which can be diſturbed by nothing foreign to theſe operations, without producing ſome characteriſtic phenomena; every thing has a reference to the *veſſel* itſelf, i. e. to the ſurface of our globe, whoſe diſtinct parts, as minerals, vegetables, and animals, offer maſſes, perpetually changing; here, therefore, the diſagreement of theory with facts, muſt give us great and important leſſons.*

If you, however, compare attentively meteorological phenomena with our *phyſical meaſures*, the barometer, the thermometer, hygrometer, &c. you will find yourſelf unable to reduce them to any *law*, that can be expreſſed by the range of theſe inſtruments: which ſhews more evidently, than any thing that can be ſeen in our laboratories, the neceſſity of admitting other combinations, than thoſe that are known, and even perhaps other ingredients.

The meteorological phenomena, whoſe cauſes we have yet to explore, are thoſe that are moſt common and the moſt important to terraqueous phyſics. They are the changes of *heat* independent of ſeaſons and latitude, thoſe of *winds*, and the variations in the heights of a local *barometer*; the viciſſitudes of *rain*, and *fair weather; aerial electricity*, and *magnetiſm*; the relations of the ſtate of the *air* to our *ſenſations*; the ſmall connection we find between vegetation, (as well in general, as for certain particular products) and the different remarkable characters of the ſeaſons.

All

* De Luc, Idees ſur la Meteorologie, a work that ſhould be fully conſidered by all who mean to underſtand the ſubject, and to which I am indebted for a great part of the Lectures on Meteorology.

All theſe grand lines in the operations of nature on our globe are to us, with reſpect to the producing cauſes, as a ſealed book.

Theſe obſervations on the *chemiſtry* of nature are by no means deſigned to leſſen your eſteem for that of our laboratories, which is certainly one of the principal ſources of all the true ſcience we poſſeſs. They are deſigned to ſhew you, that the ſmalleſt meteorological phenomena ſhould be ſtudied with as ſcrupulous an attention, as that we pay to the modifications of a little *air* in our cloſe veſſels; for it is theſe phenomena which ſhould guide us in our reſearches into the nature of the latter.

In the atmoſphere every cauſe produces it's effects: the *ſubtil fluids* are there diſtributed according to their natural tendencies; and can form or deſtroy themſelves differently, in different times, different ſoils, different climates: the winds, which have ſeldom been conſidered, but as more or leſs violent, warm, or humid, may, with reſpect to theſe fluids, anſwer more important purpoſes, than what have yet been attributed to them. In a word, great general cauſes act in the atmoſphere from which our confined air is ſecluded. It is therefore only by letting *meteorology* and *chemiſtry* go hand in hand, that we can hope to be ſecure from error in either purſuit, or be enabled to make advances towards real knowledge.

Our reſearches into the nature of theſe intereſting objects will be ever vague, and of courſe attended with but little ſucceſs, till we have ſome certain theory on the nature of expanſible fluids, and in general of all *phyſical agents*. Here it may be proper to obſerve, that we commonly join to *phyſical laws* the idea of their being an *explanation of phenomena*: but this notion is erroneous, for all phyſical laws, not excepting even thoſe of gravity, are only *generaliſations*. We are now acquainted with

with many phenomena, where the real *agents* manifeſt themſelves, and whoſe laws flow from the nature of theſe *agents*: it is to ſuch as theſe only that the idea of a *phyſical explanation* can be attached. Thus, to aſſign to *phenomena* a real and determined *agent*, acting in a certain manner, and from which certain effects are the natural conſequences; and to ſhew that the laws of theſe phenomena correſpond thereto; is really to *explain* the phenomena. Now we know phenomena enough, thus connected with real cauſes, to enable us by analogy to extend very far the real links that connect effects one with the other in nature; remembering always to conſider true *agents* as being more and more general, the further they are removed from us, or ſubordinate as they approach us. Theſe are the proper objects to occupy the attention of a *rational philoſopher*, as they alone can form the foundation of *rational phyſics*, one that will give us efficacious aid in our experimental reſearches. What would become of practical mechanics, if in elementary mechanics there was no ſyſtem of it's *agents*, no laws previouſly determined, which they follow when they operate? And yet, though all is *action* in nature, philoſophers ſcarce think of looking for the *true agents*.

Among the means of advancing our knowledge in *meteorology*, are the *inſtruments* that have been contrived to aſcertain the variations in the weight of the atmoſphere; it's changes with reſpect to *temperature*; the degrees of *humidity*, &c. If every one who is in poſſeſſion of meteorological inſtruments would keep a diurnal regiſter of their ſtate, and of the correſponding phenomena of the atmoſphere, and tranſmit the reſult of his obſervations to the public, he would contribute more to the advancement of this branch of ſcience than he

he might at firſt imagine. While he was amuſing himſelf, and gratifying curioſity, he would be promoting knowledge, and probably procuring benefits for poſterity. Let no one ſuffer the apparent improbability of ſucceſs to diſcourage him from the attempt. Remember that ſcience advances by ſlow and gradual ſteps, that it's progreſs depends on the cultivation of the mind, the acquiſition of facts, the removal of obſtacles, and the exertion of individuals: the preſent is ever pregnant with the future, though the connection between them can only be found by long attention and diligent obſervation. A regiſter for preſerving what no memory can retain, becomes an authentic document, a reference from which facts may be combined and compared, and thus one of the pureſt ſources of practical knowledge. To indulge ends ſo rational, to as great an extent as the human powers can reach, and with as much enjoyment as the human mind can bear, DIVINE PROVIDENCE hath appointed the means, whereby each man's ſmall ſtock of knowledge and truth may be *communicated* to others without loſs to himſelf; and further, how it may be placed in a *common treaſury*, for every man to draw from thence whatever his occaſions or inclinations may require. Theſe ends are known to be accompliſhed, the firſt by *ſpeech*, the latter by *writing* and *publiſhing* what is written.

It may be obſerved in general, that *meteorological phenomena*, like all the durable motions of the univerſe, depend upon a *circulation of matter*. Here it is principally carried on by changing of water into a new form, and a regeneration of it again into it's primitive form. It goes off from the ſurface of the earth in the form of a rare inviſible expanded vapour; in the atmoſphere it's ſtate is changed, and from that of vapour to an

aeriform

aeriform fluid; by ſome unknown cauſe it is again changed into miſt and clouds, is then gathered into drops when it falls, and in this form it returns to the place from whence it came, to take it's turn once more in the common courſe of evaporation, and be again and again circulated to the great promptuary of the world.

The principal objects therefore of inquiry are, 1ſt, In what manner the atmoſphere is ſupplied with humidity? 2dly, What cauſes and what prevents *inviſible humidity* from being formed into clouds? And, 3dly, What occaſions and what prevents viſible clouds from being precipitated in rain? That is, to know the various *ballancings of the clouds*, and learn how ſuch ponderous materials are ſuſpended in the air? And *how the waters are bound up in the thick clouds?*

As one of the principal means of anſwering theſe inquiries are the inſtruments uſed to diſcover the changes in the atmoſphere, I ſhall firſt deſcribe theſe, and then proceed to give you ſome account of meteorological phenomena. The inſtruments in general uſe are, 1. a barometer: 2. a thermometer: 3. an hygrometer: 4. a rainguage: 5. an electrometer.

OF THE BAROMETER.

In treating of the barometer, I ſhall have only to enlarge on ſome circumſtances that were but ſlightly noticed, when I explained this inſtrument to you in my ſecond Lecture. The barometer, as I there ſhewed you, conſiſts of a ſtrait glaſs tube, about thirty-two inches long, open at one end and cloſe at the other; this tube is firſt filled with mercury, and then inverted in a baſon of the ſame fluid, by applying a finger to the open end, ſo as to prevent any air from entering the

the tube; when the open end of the tube is immerged beneath the ſurface of the mercury in the baſon, the finger is withdrawn; the tube being now ſet upright, the mercury deſcends, leaving the top of the tube, and ſubſiding till it has attained a certain diſtance from the ſurface of that in the baſon; this is more or leſs, according to the ſtate of the air at the time of making the experiment. The tube is then fixed to a frame with a ſcale annexed, to ſhew at all times the height of the mercurial column.

From the method of filling the tube, the air is excluded from the top of the column, or that part of the tube above the ſurface of the mercury in the tube. The external air preſſes upon the quickſilver in the ciſtern, and ſuſtains, by it's preſſure in a contrary direction, a column equal in weight to itſelf. For it is evident, that the mercury *endeavours to deſcend* with a force equal to that by which *it's deſcent is prevented.* In other words, the preſſure of the atmoſphere on a given ſurface is equal to the weight of a column of mercury, whoſe baſe is the given ſurface, and height equal to that of the atmoſphere. The height of the mercury is therefore an adequate meaſure of the weight or preſſure of the air upon a ſurface equal to the baſe of the tube containing the mercury.

The truth of this reaſoning, I have confirmed by ſeveral experiments exhibited in my ſecond Lecture; you there ſaw, when a barometer was placed under a receiver, that in proportion as the air was exhauſted from the ſurface of the mercury in the baſon, the column in the tube deſcended till at laſt they were nearly on the ſame level. The barometer-guage exhibited the reverſe of this experiment, for you there ſaw the mercury riſe in the tube in proportion as the air was exhauſted therefrom, the open air preſſing at the ſame time

upon

upon the ſurface of the mercury in the baſon. What is thus exhibited by our inſtruments is confirmed by nature, for the higher we aſcend in the atmoſphere, the ſhorter is the column of mercury.

The *barometer with a ſtrait tube*, as originally contrived by Torricellius, is preferable to all the ſubſequent variations in it's form. When it was found that the different heights of the mercury in the barometer were in ſome meaſure connected with the ſtate of the weather, the philoſopher and artiſt endeavoured to vary the form of the inſtrument; hence a variety of conſtructions more or leſs accurate according to the views of the inventors, and the diſtance to which they removed the barometer from it's original ſimplicity.

They thought that by augmenting *the ſcale* of the barometer, and thus rendering the variations of the mercury more ſenſible, they ſhould ſooner diſcover the minute changes of the atmoſphere, and the cauſes which occaſioned them; unfortunately by altering the conſtruction of this inſtrument, they only multiplied errors, and rendered it leſs capable of anſwering the purpoſes for which it was deſigned. Some of theſe forms may appear more *elegant* than the plain barometer, but none of them can be depended upon for keeping an accurate regiſter of the weather, or for obſerving the extent of the variation thereof in any given ſituation, or comparing the different changes at one place with correſponding ones at another. Hence it is neceſſary to point out to you what is requiſite to conſtitute a good barometer.

OF

OF SOME OF THE PRINCIPAL REQUISITES OF A GOOD BAROMETER.*

1. It is requiſite that the height of the column of mercury be altered by no other cauſes but the changes that ariſe from the preſſure of the air, and that theſe changes be truly indicated.

2. That the variations in the height of the column be aſcertained by a known meaſure.

3. That the column of mercury be ſuſceptible of the ſmalleſt alterations in the weight of the air.

In order that the column of mercury, in the tube, may be affected by no other cauſe than the preſſure of the air, it is abſolutely requiſite, that the upper part of the tube, and the mercury itſelf, be entirely freed from air; for if there be any air between the upper ſurface of the column of mercury and the ſealed end of the tube, it will be the ſource of many errors and much irregularity. The included air will act as a counterpoiſe againſt the weight of the atmoſphere, and to a certain degree counteract it's preſſure, and, therefore, render the indication of the inſtrument uncertain and erroneous. This included air, being alſo often combined with humidity, expanded by heat, or contracted by cold, acts differently at different times: the only method of preventing theſe errors, and perfectly excluding the air from the barometer, is by *boiling the mercury in the tube:* an operation which is carefully performed in all the beſt inſtruments.

TO BOIL THE QUICKSILVER IN A BAROMETER TUBE.†

Chooſe a tube not leſs than three feet long with

* See my Diſſertation on the Barometer and Thermometer, 1790.

† De Luc's Recherches ſur les Modifications de l'Atmoſphere.

with a bore about three or four twentieths of an inch in diameter, but not more; and that it may be ſufficiently ſtrong, it ſhould be nearly as thick on all ſides as the diameter of the bore. Let this tube be nicely ſealed or cloſed at one end, and as clean as poſſible; fill the tube with pure mercury to within two inches of the top, and then hold it with the ſealed end loweſt in an inclined poſition over a chaſing-diſh of burning charcoal, placed near the edge of a table, in order that all parts of the tube may be expoſed ſucceſſively to the action of the fire, by moving it obliquely over the chaſing-diſh. The ſealed end is to be firſt gradually preſented to the fire; as ſoon as the mercury becomes hot, the internal ſurface of the tube will be ſtudded with an infinite number of air-bubbles, giving the mercury a kind of grey colour; theſe increaſe in ſize by running into one another, and aſcend towards the higher parts of the tube, where meeting with a cooler part of the fluid they are condenſed and nearly diſappear. In conſequence however of ſucceſſive emigrations towards the upper parts of the tube which are ſucceſſively heated, they finally acquire a bulk which enables them in their united form entirely to eſcape. When the firſt part of the tube is ſufficiently boiled, move it onward by little and little through the whole length of the tube. When the mercury boils, it's parts ſtrike againſt each other, and againſt the ſides of the tube with ſuch violence, that a perſon unacquainted with the operation naturally apprehends the deſtruction of his tube.

The great advantages that reſult from this operation appear to be theſe: the whole body of the mercury, and the interior ſurface of the tube, are hereby freed from all the minute and imperceptible particles of duſt and moiſture which they generally contain, and of the little *atmoſpheres*

that

that are ſeen to ſurround them; which, during the tumultuous motions of the mercury, are viſibly driven up towards it's ſurface, and expelled. The tube and the mercury are deprived likewiſe of all the air that can be expelled from them, and particularly from the ſurface of the former, by the violent heat and agitation of boiling quickſilver. As that heat too is a determinate or fixed quantity, it's effects in expelling the air from different tubes will be nearly equal; ſo that though ſome ſmall portion of air may ſtill be left in them, there can be no difference in the quantity of it remaining in different tubes thus uniformly treated. Accordingly, the barometers thus prepared not only ſtand higher than thoſe which have not undergone this proceſs; but at the ſame time they pretty accurately correſpond with each other.

M. De Luc obſerves, that the greateſt part of the air which is expelled during the proceſs, proceeds from the internal ſurface of the tube, where it ſeems to have formed a thin *ſtratum* or *lining* of air, which cannot be diſlodged from thence by the mercury introduced into the tube in the common manner, but requires the violent heat and agitation of boiling quickſilver to detach it. But it is very remarkable, that, after this *aerial coating* has been once effectually ſeparated and expelled, if the tube be emptied, and ſome other, even cold, mercury be introduced into it, the barometer thus *extemporaneouſly* made, will be nearly as perfect, or as free from air, as before. It will ſtand nearly as high as it did when it contained the mercury, that had been boiled in it; if the ſame proceſs be now repeated, it will not be ſtudded with bubbles of air, as in the former operation; when the mercury has been completely boiled, the tubes may be cut off to their proper length by a file.

When tubes are well boiled, the mercury

generally remains ſuſpended at top, and will not deſcend to it's proper level without ſhaking the tube to bring it down.

That the changes in the height of the mercurial column may be truly aſcertained, it is neceſſary to know at all times the exact diſtance of the ſurface of the mercury in the tube, from the ſurface in the reſervoir or ciſtern.

The firſt point of the meaſure muſt commence from the ſurface of the mercury in the ciſtern; but this ſurface is variable, for when the mercury deſcends, a quantity of it falls into the baſon, and raiſes the ſurface thereof; and on the contrary, when it riſes, a quantity is taken out of the ciſtern, and the ſurface thereof is lowered. The ſcale of inches to the barometer is fixed; but the ſurface of the mercury in the ciſtern from which it originates is continually varying. To remedy this evil, it is neceſſary that the lower ſurface ſhould be always kept at the ſame height from the diviſions on the ſcale affixed to the inſtrument. This is effected by means of a floating guage, which was firſt applied to the barometer by *my Father*, though others have, ſince his time, aſſumed the merit to themſelves. By means of the floating guage, the ſame ſcrew that renders the barometer portable, regulates the ſurface of the mercury in the ciſtern, ſo that it is always at the place from whence the diviſions on the ſcale commence. This guage is never applied to the common portable barometers, but only to thoſe of the beſt kind.

Another circumſtance neceſſary to be attended to in very accurate obſervations, is the effect of heat and cold on the barometer, as by theſe the mercurial column is either dilated or contracted; for as all bodies expand and occupy larger ſpaces when their temperature is increaſed, the mercury in the barometer will, when heated, be ſpecifically

cally lighter, and will consequently ascend from that cause, though the pressure of the air should remain unchanged; and therefore, in order to know accurately the effect of the air's pressure on the barometer, it is necessary to correct the height by the addition or subtraction of a quantity equal to the influence of the temperature of the air thereon. In some cases a scale of correction is applied to the thermometer accompanying the barometer, and which is indeed a necessary companion to it.

2d. Condition. That the scale should be of some known measure. It would have been totally unnecessary to have mentioned this condition, had it not been to prevent you from being imposed upon by venders of imperfect instruments. Some of these instruments have no determinate scale affixed to them; and those which have a scale, have one that is in general ill graduated and erroneously placed, so that no comparative observations can be made with them; and often, indeed, no observation at all; as from the small bore of the tube, they act as a thermometer, as well as a barometer. I have already observed, that by enlarging the scale, error is multiplied, and uncertainty produced.

3d. Condition. That the smallest changes in the height of the column of mercury may be discerned.

To measure the smallest changes, a nonius division moves with the index, by which each inch is subdivided into 100 parts, and the height of the mercury is accurately obtained without any danger from parallax, by the peculiar construction of the index.

Of the Nonius.

The scale of inches is affixed to the right side of

of the tube, the zero or beginning of the ſcale being at the ſurface of the mercury in the ciſtern, the index and it's nonius plate ſlide up and down in a groove, which is parallel to the line of inches, that the index may be ſet at any time to the upper ſurface of the column of mercury.

Each inch, or line of inches, is divided into ten parts, which are again ſubdivided into ten, by means of the nonius ſcale; the whole inch being thereby divided into 100 equal parts.

TO READ OFF, OR ESTIMATE THE DIVISIONS OF THE NONIUS SCALE.

1. If that edge of the nonius ſcale, which is in a line with the index, coincides exactly with any diviſion on the line of inches, that diviſion expreſſes the height of the index from the ſurface of the mercury in the ciſtern, in inches and tenths of inches. But 2dly, If the foregoing edge does not coincide with any diviſion, you muſt look for that diviſion of the nonius, which coincides with a diviſion in the line of inches, and the number on the nonius ſhews how many tenth parts of the tenth, the index or edge has paſſed the laſt decimal diviſion. Thus for example, ſuppoſe the edge of the nonius was to point ſomewhere between 29 inches 8 tenths, and 29 inches 9 tenths; then if by looking at the nonius, you obſerve the coincidence at 5, it ſhews the altitude to be 29 inches 8 tenths, and 5 parts of another tenth, or 29, 85.

OF THE COMMON PORTABLE BAROMETER.

This inſtrument, when made with care, will anſwer for general and domeſtic obſervation, but is not ſufficiently accurate for philoſophical purpoſes.

It

It conſiſts of a tube, of a proper length, accurately filled with mercury; the lower end of the tube is glued to a wooden reſervoir, the bottom of which is formed of leather; into this reſervoir the ſuperfluous mercury deſcends, and the air, by preſſing upon the flexible leather at the bottom of the reſervoir, keeps the mercury ſuſpended at it's proper height. This reſervoir is concealed from the eye by a neat mahogany cover, or box. This tube and reſervoir are placed in a frame, on the upper part of which is a ſilvered braſs plate; on the right hand ſide of this plate is a ſcale of inches, reckoned from the ſurface of the mercury in the ciſtern; each inch is divided into ten parts. Cloſe to the line of inches there is a ſlit, or groove, for conveniently ſliding the nonius ſcale and index up and down. The upper edge of the index and nonius ſcale are in a line. It is the upper edge of the index that is to be ſet to the upper ſurface of the mercury. On the left-hand ſide of the plate, the words FAIR, CHANGEABLE, RAIN, are engraved. At the bottom of the frame there is a ſcrew paſſing through the mahogany box which covers the reſervoir: a flat round plate is placed upon the end of the ſcrew within the box; this end is deſigned to preſs upon the leather bag, and force the mercury up to the top of the tube, and thus prevent it from ſhaking, or violently ſtriking againſt the top of the tube when tranſported from one place to another.

To use the Portable Barometer.

1. Suſpend it againſt a wall, or wainſcot, ſo that the tube may be perpendicular to the horizon.

2. Unſcrew the ſcrew at the bottom of the frame as low as it will go, and the mercury will

fall to it's proper height, and be obedient to the changes in the weight of the air.

3. Set the upper edge of the index, ſo as to coincide with the ſurface of the mercury in the tube, and the nonius ſcale will point out the height of the column.

4. Before every obſervation, ſtrike the frame gently with the knuckles, to diſengage the quickſilver from the tube.

5. If the barometer is to be moved from one place to another, turn the ſcrew, till the mercury is preſſed by it againſt the top of the tube.

DEFECTS OF THE COMMON PORTABLE BAROMETER.

It is neceſſary here juſt to mention ſome of the defects of this kind of barometer, in order to render the advantages of the better kind more conſpicuous.

1. It cannot be ſo adjuſted as to be ſure that the diviſions on the ſcale are at that height from the mercury in the ciſtern, which is expreſſed by the numbers affixed to them. As when the mercury falls in the tube, it riſes in the reſervoir; and when it riſes in the tube, it falls in the reſervoir; it's diſtance is perpetually varying from the diviſions of the ſcale.

2. The tenſion of the leather forms a conſiderable reſiſtance to the preſſure of the atmoſphere.

OF THE BEST PORTABLE BAROMETER.

This barometer, like the preceding, conſiſts of a glaſs tube, properly filled with mercury, having the lower end fixed to a wooden ciſtern, with a leather bottom, and this tube and ciſtern placed in a mahogany frame.

On

On the upper part of the frame a braſs plate is placed; on the right-hand ſide of the tube a ſcale of inches is graduated on the plate, the beginning of the ſcale being at the ſurface of the mercury in the ciſtern: each inch is divided into ten parts, which are again ſubdivided into tenths by the nonius ſcale.

The nonius plate carries two indexes, exactly ſimilar to each other, one placed before the tube, the other behind it. The indexes may be raiſed or depreſſed, by turning the key, which fits into a ſmall hole in the frame, directly under the groove of the nonius plate.

On the left hand of the tube a ſmall thermometer is placed, with Fahrenheit's ſcale; there is an index to the thermometer, which may be ſet by the ſame key as the barometer, only putting it into the ſmall hole under the thermometer, and turning it round till the index points to the mercury in the thermometer. A ſcale for correcting the expanſion of the mercury in the barometer, is often graduated cloſe to the ſcale of the thermometer.

The upper part of the barometer is covered with a glaſs plate, to prevent the ſilvering of the plate from being injured by dirt, or being corroded by the action of the air.

Of the lower Part of the Barometer.

The lower end of the tube is immerſed in the ciſtern which contains the mercury; the ciſtern is covered with a mahogany box; at the bottom of the frame is a ſcrew, to raiſe or lower the ſurface of the mercury; at the top of the ciſtern is a hole, which is fitted with an ivory ſcrew, to be placed there occaſionally for the conveniency of tranſporting

porting the inſtrument ſafely from one place to another.

The guage conſiſts of a ſmall ſtem of ivory, ariſing from a float of the ſame ſubſtance; a circular diviſion is cut round this ſtem; the ſtem paſſes through a ſhort cylinder of ivory, which is cut open in front; on this front two ſmall diviſions are cut; at the bottom of this cylinder is a male ſcrew, to fit the female ſcrew of the ciſtern; the upper part of the guage is protected by a tube of glaſs perforated at top.

TO USE THIS BAROMETER.

1. The barometer being fixed in a perpendicular poſition, unſcrew the ſcrew at bottom as far as it will go without forcing it.

2. Take out the ivory ſcrew at the top of the ciſtern, and place it between the ſcroles on the upper part of the frame.

3. Screw the guage into the place from whence the ivory ſcrew was taken.

4. Screw up that ſcrew which is at the bottom of the frame, until the line on the float exactly coincides with the two lines on the front of the ivory cylinder.

5. Strike the barometer gently with the knuckles, and then ſo ſet the lower edge of the front index to the convex ſurface of the mercury that it may be at the ſame time in a line with the edge of the index behind the tube; and the nonius will then give the true height of the mercurial column, from the ſurface of the mercury in the ciſtern.

6. The preceding rule for ſetting the guage muſt be complied with previous to every obſervation.

7. If

7. If the barometer is to be tranſported from one place to another, the guage muſt be removed, and the ſolid ivory ſcrew inſerted in it's place; after which, the mercury in the tube may be forced gently up to the top thereof, by the ſcrew at the bottom of the frame.

Of the Scale of Correction.

This ſcale is placed cloſe to that of the thermometer; but on the right-hand ſide, the zero, or 0 degree of this ſcale, correſponds to the 55th degree of the thermometer.

1. If the barometer is at 30 inches, and the thermometer at 55 degrees, no correction is neceſſary.

2. But if the thermometer be under 55, and the barometer at 30 inches, you muſt add to the height of the barometer as many of the 100ths of inches as are on the ſcale of correction oppoſite to the degree of the thermometer.

3. If the thermometer be above 55, and the barometer at 30 inches, you muſt ſubtract as many 100ths as are indicated by the given degree of the thermometer on the ſcale of correction.

4. The ſcale applied to the thermometer anſwers for the general range of meteorological obſervations; but if the height of the barometer be very far diſtant from 30 inches, it will be neceſſary to make uſe of the rule of three, in order to obtain the true correction: for inſtance, let the barometer be at 26 inches, which we will call P, c the correction indicated by the thermometer, x the true correction: then as 30 : P : : c : x; or $\frac{Pc}{30}=x$, which is to be added to the height of the barometer whenever the thermometer is under 55 degrees, but to be ſubtracted when it is above 55.

OF THE THERMOMETER.

No inſtrument is of more importance for making diſcoveries in meteorology than the thermometer, as it points out the temperature or degree of heat of the air and other bodies. Heat and cold are perceptions, the ideas of which we acquire by the ſenſes. Our ſenſations are however inadequate meaſures of heat and cold, for they depend not only on the ſubſtance which excite them, but on the actual ſtate of our bodies at that time: we cannot, therefore, conclude the exact identity or ſimilarity of the cauſe, from the ſameneſs of the ſenſations, unleſs we can be aſſured that our bodies are in the ſame ſtate: if they be not, the ſame objects will produce very different ſenſations. Thus if the hand be plunged into lukewarm water, this water will appear cold if the hand be warm; but if the hand be cold, the water will appear to be warm; though in both caſes it poſſeſſes the ſame temperature.

Our ſenſes are, therefore, both imperfect and deceitful meaſures of heat; and we cannot aſcertain, by their means only, the ſtate of the ſurrounding bodies with reſpect to heat or cold. This occaſioned philoſophers to ſeek for ſome method by which they might determine the temperature of bodies with more certainty. This they found in the property of fire to dilate and expand all bodies, whether ſolid or fluid; and of cold, to contract or condenſe them. This expanſion and contraction is conſidered as a meaſure infinitely more certain of the degrees of heat and cold, than the ſenſes.

It would appear from this expanſion, that *fire*, when it is agitated by that motion which we call *heat*, always acted as if it wanted more room, and this in ſuch a wonderful manner, as if every particle

cle of ſpace in which it exiſts were a radiant point or center, from whence it ſpreads forcibly outwards in every direction; and conſequently when fire, thus acting, is admitted into the pores of bodies, their parts muſt be ſtretched out, and their dimenſions every way increaſed, according to the degree of fire by which they are acted on. Some idea of the force of this expanſion may be gained by conſidering how vaſt a weight may be ſuſpended from a bar of iron, or braſs, in a vertical poſition, without ſeparating the parts of the metal, or overcoming the force with which they cohere. Now this, fire eaſily executes, ſo far relaxing the texture of braſs and iron, that their parts will fall aſunder with nothing but the force of gravity.

Thermometers are inſtruments which meaſure the degree of heat by the expanſion of bodies. Fluids are thoſe generally uſed, becauſe they are dilated more readily than ſolids; and quickſilver is preferred to other fluids, becauſe it's expanſibility is not affected by the different circumſtances in which it is placed; it does not ſoil the tube like many other fluids, and at the ſame time affords an extenſive ſcale of diviſions.

A thermometer is a tube of glaſs, the end of which is blown into a ball or cylinder; the ball, and part of the tube, is filled with mercury. The fluid in the ball dilates by the heat, and contracts with the cold, which occaſions the fluid in the tube to riſe and fall; and the ſmaller the bore of the tube is in proportion to the ball, the more viſible will be the riſe of the fluid by a ſmall expanſion. We may, therefore, conſider this inſtrument as a convenient meaſure of the changes of heat and cold, which is ſhewn by the ſcale to which the tube is affixed.

But it is not ſufficient to have found a meaſure of heat; it muſt be univerſal, always ſpeak-

ing the ſame language, and awaking the ſame ideas in the mind, in all places, and at all times.

To this end it is neceſſary, 1. That this meaſure ſhould begin from a known and determinate point. And, 2. That another point, equally certain as the firſt, but at ſome diſtance from it, be fixed upon. And, 3. That the ſpace between them be divided into a certain number of parts, which in all inſtruments will have a conſtant proportion.

It has been fully proved, that the *temperature of freezing water*, or *melting ice*, is conſtantly the ſame in all places, and at all times. The ſame may be ſaid of *boiling water, under a given preſſure of the atmoſphere*. If, therefore, the ball of a thermometer be plunged into melting ice, and afterwards into boiling water, and left in each till it acquires their temperature, and marks are made at the reſpective heights at which the mercury ſtands in each, two fixed points will be obtained. To be more particular:

When ice is at the melting temperature, whatever be the *heat* you apply to it, it *does not become hotter*; a thermometer in the middle of the maſs, continually ſtands at the thawing point as long as any of the ice remains about it, ſo that the ſame cauſe, which in other circumſtances *would produce heat*, here only produces *liquifaction*. Hence it is, that melting ice, or freezing water, is ſo well adapted for giving one of the fixed points of a thermometer. The quantity of *fire abſorbed by ice* in melting, is ſuch as would increaſe the temperature of the water *about* 140 *degrees*: converſely, *water* may be cooled 18 *degrees below the freezing point*, without freezing: congelation cannot take place till a certain portion of the combined or latent fire is diſengaged; when any part does congeal, the fire let looſe, raiſes the thermometer

to

to the freezing point, and it continues there till the water is frozen; after which, as the water in the first case, so the ice in the latter, obeys the external temperature.

Continual accession of fire arrives at water when boiling, without increasing the heat thereof; for *ebullition*, under any given pressure, cannot take place, till the vapour produced in the liquid, has obtained a degree of expansive force, sufficient to raise the liquor into bubbles; under that pressure, and so long as the vapour retains this heat, it must continue capable of resisting the same pressure; as the heat abates, a decomposition takes place, which occasions the opake steam over boiling water.

These principles explain the *fixity* of the boiling point, for vapours cannot be formed within the mass, unless they have sufficient expansive force to displace or raise it into bubbles: they cannot acquire this force, till the heat is arrived at a certain point, and as soon as they have acquired it, they escape in virtue of that expansion: further accession of fire passes off in the same manner, and only accelerates the evaporation.

Though *boiling water* under the same pressure has always the same heat, it may be made, before it does boil, to receive a greater heat, than it can retain when it does boil. In a vessel with a very narrow orifice, filled with water, well purged of air, though the water sustains no other pressure than that of the atmosphere, yet it's particles meet with so much resistance to their separation, that Mr. de Luc found it would receive, without boiling, a heat 22 degrees above the boiling point; as soon as vapours could form themselves, their expansive force was so great, that they pushed a large quantity of water out of the vessel, in the way of explosion,

explosion, but the remainder was immediately reduced to boiling heat.

The vapours of boiling water arise from *within* the mass, but water may yield from it's surface vapours of an equal expansive force, provided they are *confined* in a place of equal temperature with themselves. Thus if water be introduced above the mercury in a barometer, the vapours it produces in a temperate warmth will press down the mercury nearly half an inch. In the heat of boiling water, they will depress it to the level of the mercury in the bason; being then become equivalent to the pressure of the atmosphere in a greater heat, they will depress it below the level, and escape at the bottom of the tube, the water giving no signs of ebullition to the last.

In making thermometers, care should be taken that the tubes used for that purpose be very clean, and very dry; the next thing is to examine whether the bore of the tube is equal and cylindrical throughout; this is easily performed, by immerging one end of the tube in mercury, and taking it out, previously stopping the other end with the finger; by this means, a small portion of the mercury will enter the tube, more or less in proportion to the depth the tube is immerged; measure the length of this portion of mercury, and then slide it backwards and forwards in the tube. If the length thereof is the same in all parts, the tube is a regular cylinder; but if otherwise, the diameter varies, and the tube cannot be used to form a good thermometer, unless the divisions on the scale are proportioned to the different lengths of this mercurial cylinder.

The tube being chosen, the bulb is to be blown; if the tube was very regular, you may now begin to fill it; if not, you must find the proportion of the inequalities to adapt the divisions thereto;

to; to this end tie a paper funnel over the end of the tube, and pour a ſmall quantity of mercury therein, then hold the bulb over the flame of a candle or lamp, and let ſome of the air paſs out of the bulb through the mercury; take it now from the lamp, and as the ball cools the mercury will begin to enter the tube; admit about half an inch, take the exact meaſure thereof, meaſure the length of this portion in different parts of the tube, and you will thereby obtain data for proportioning the diviſions to it's inequalities.

If you have any reaſon to ſuſpect that there is moiſture in your tube, it would be proper before the preceding operation to clean it; this may be done by laying the tube on a plate of iron, or over a chaffing-diſh in which there is only a ſmall fire mixed with cinders; it ſhould be continued there till it is ſo hot that you muſt uſe a glove or a ſmall pair of pincers to hold it, taking care not to warm the bulb. This proceſs dilates the included air, conſumes ſmall particles of dirt imperceptible to the eye, and evaporates moiſture. While things are in this ſtate, ſuddenly heat the bulb, and the air being thereby dilated, drives before it all theſe impurities, and leaves the tube as clean as you can deſire.

To fill the bulb and tube, tie on a paper funnel as before, and put ſomewhat more mercury therein, than you think will fill the thermometer; hold the bulb over the flame of a lamp or a ſmall candle newly ſnuffed, this will expand and force part of the air from the bulb; when you think a ſufficient quantity is expanded, withdraw the tube from the candle; in proportion as the bulb cools, the remaining air will be condenſed, and the ſpace it occupies will be occupied by the mercury; by thus alternately cooling and heating the bulb, it is at laſt completely filled.

When the bulb is nearly filled, you muſt boil the mercury therein, by applying it over the flame of a lamp, or that of a ſnuffed candle. The air included in the mercury, and that which lines the tube, dilates itſelf, is collected in ſmall bubbles, and expelled by the firſt ebullition; when the mercury boils violently, a great part of the contents will ruſh up the tube into the paper reſervoir. Remove the bulb from the flame, and repeat the operation, till the diminiſhed noiſe and agitation ſhews that it is deprived of it's air and moiſture.

After the boiling is completed, and the tube cool, plunge it in melting ice or ſnow, which gives the temperature of 32°. Take off the funnel, and hold the bulb in the hand, and afterwards in the mouth; the heat thereof will cauſe ſome of the mercury to drop out of the tube; cool it again to 32°, and mark where the mercury ſtands. The diſtance between this mark and the top of the tube, meaſures the interval between freezing and blood heat, or 32 and 95, that is 63°, and will conſequently point out whether the degrees will be large or ſmall, and what extent your ſcale is capable of.*

When the number of degrees to which the length of the tube will extend is thus known, you may ſettle whereabouts you will have the freezing point, which may be nearer or further from the bulb, according as your inſtrument is deſigned to meaſure great or ſmall degrees of heat or cold. Now prepare the upper part of the tube for ſealing, by drawing it out to a fine capillary tube; then heat the bulb in the candle till a few particles of mercury have fallen off the top of the tube, and afterward try if the freezing point is ſufficiently near

* Nicholſon's Firſt Principles of Chemiſtry, p. 26, 27, 28.

near the bulb; if it be not, you muſt repeat the operation, being careful however not to throw out too much mercury at a time. Have two candles now ready, one to heat the ball, the other to cloſe the tube. The blow pipe being in readineſs, the upper part of the tube near the flame of one candle, and the bulb near the flame of the other, the mercury will riſe, and at laſt begin to form a globule at the point of the capillary tube; at this inſtant the bulb muſt be withdrawn from the flame of the lower candle, and the flame of the upper one be directed by the blow-pipe upon the point of the tube. This will be immediately ignited, and will cloſe by the melting of it's parts before the mercury has perceptibly ſubſided. When the mercury has fallen, the ſealing may be rendered more ſecure by fuſing the whole point of the tube till it becomes ſound.

To ſettle the *freezing point*, you have only to immerge the thermometer ſo deep in melting ſnow or ice, that the mercury may be ſcarcely viſible above the ſurface, and then carefully mark the place at which it ſtands. For the *boiling point*, the Royal Society adviſe a veſſel to be provided ſomewhat longer than the thermometer, with a cover and two holes therein; one about an inch in diameter for the ſteam to eſcape, the other ſmaller to hold the thermometer tube. When this is uſed, the thermometer muſt be faſtened in the cover, ſo that the eſtimated place of the boiling point may be juſt above the hole; water muſt then be put in the veſſel, but ſo as not to touch the bulb of the thermometer, when the cover is placed on. The cover being put on, and a thin plate of metal laid on the ſteam hole, you are to make the water boil by heat applied to the bottom only; the thermometer will thus be ſurrounded by ſteam which

will raiſe it's temperature to the boiling point, and this muſt be carefully marked on the tube.

Fahrenheit's ſcale is that which is uſed in England: the freezing point is called 32, the boiling water point 212; ſo that there are 180 degrees, or diviſions, between them, which may be extended upwards and downwards, as far as is neceſſary.

Foreigners uſe *Reaumur*'s, or rather *De Luc*'s ſcale, where the freezing point is called 0, and the boiling water point 80.

Two thermometers are neceſſary for accurate obſervation; one to be ſuſpended within doors, near the barometer; the other out of doors. That without doors ſhould be placed at the north ſide of the houſe, or where it will be ſheltered from the rays of the ſun.

I have already ſhewn you,* that the *increments of expanſion in a mercurial thermometer are nearly as the increments of heat*; or in other words, that the dilatations and contractions of the fluid are nearly proportional to the quantities of fire, which are communicated to, or ſeparated from the ſame homogeneous bodies, as long as they remain in the ſame ſtate. Thus the quantity of fire required to raiſe a body four degrees in temperature by the mercurial thermometer, is nearly double what is required to raiſe it two degrees, and four times what is neceſſary to raiſe it one. This is proved by putting a thermometer firſt in cold water, and then into water heated to any degree, noting the altitudes; then putting equal quantities of theſe two waters together, which will give a mean heat, and the mercury in the thermometer will ſtand at the mean altitude between the two before obſerved; this is found to be true, whatever be the temperatures of the two parts of water.

Though in the ſenſe here explained the thermometer

* Vol. I. p. 249, 250; ſee alſo p. 401 to 404.

mometer is an accurate meaſure of heat, yet I have alſo ſhewn you, that it can only indicate the proportions of that action of fire by which bodies are *expanded*, but is by no means a meaſure of the whole quantity of fire diſengaged, diſplaced, or abſorbed; properly ſpeaking, it is therefore only a ſcale of expanſion indicating certain tranſlations and transfuſions of the igneous fluid.

It may be proper to obſerve to you, that glaſs is dilated and contracted by heat and cold together with the fluid, and conſequently the apparent variations in the dimenſions of the fluid are the difference between the real cotemporary expanſions, or ſum of the cotemporary contractions of the glaſs and the fluid. The changes ariſing from theſe cauſes, are too inconſiderable to be worthy of notice in the general uſe of this inſtrument; the change of dimenſion in the glaſs is prior to that in the fluid; hence the fluid is found to ſink before it's riſe, upon an increaſe of temperature; and if the bulb be large, ſome time may elapſe before the fluid acquires the ſame temperature with the glaſs. The preſſure of the atmoſphere on the outſide of the bulb not being counteracted by any air within, will affect it's magnitude, diminiſhing it as the preſſure is increaſed. The variation on the ſcale occaſioned by this cauſe is, like the preceding one, very ſmall, being never above one-tenth of a degree.

Of the Rain-Guage.

It is neceſſary, towards forming a ſyſtematic idea of the weather and it's various changes, to meaſure the quantity of rain which falls upon the earth; and this is done by what is called a *rain-guage*.

The rain-guage is a very ſimple inſtrument, conſiſting of a ſquare tin funnel of twelve inches

 diameter,

diameter, communicating with a tube or cylinder of tin, into which the rain is conveyed by the funnel. The depth of the water is meaſured by a rule fixed to a float; this rule paſſes through the center of the funnel. The diviſions on the rule ſhew the number of cubic inches of water that have fallen in a given time on a ſurface of one ſquare foot.

To uſe the rain-guage, ſo much water ſhould be firſt poured in as will raiſe the float, ſo that the zero, on the rule, may exactly coincide with the aperture of the funnel. The funnel is ſo contrived, as to prevent the water from evaporating.

This guage ſhould be fixed down firmly in a place, where, whatever wind blows, the fall of the rain may not be intercepted by the houſe, or any other impediment.

OF THE HYGROMETER.

The *hygrometer* is an inſtrument, intended to diſcover the moiſture contained in the atmoſphere.

As the ſubſtances that are affected by moiſture are very numerous, ſo alſo are the contrivances that have been executed to indicate the degrees of moiſture, and render ſenſible the ſmalleſt variations in the ſubſtances influenced thereby. Thus, wood expands by moiſture, and contracts by dryneſs; on the contrary, chord, catgut, &c. contract by moiſture, and lengthen by dryneſs; conſequently the contraction and expanſion of theſe ſubſtances indicate different ſtates of the air with reſpect to moiſture. The twiſted beard of a wild oat, with a ſmall index fixed to it, moveable againſt a ſcale, makes a very good hygrometer; for, the twiſting being affected by the variations of moiſture, moves the index.

Mr

Mr. de Luc, who has laboured more on this ſubject, and with more ſucceſs than any other man, after making an immenſe number of experiments to find out a ſubſtance, whoſe expanſion increaſes moſt, nearly in proportion to the quantity of moiſture imbibed, found that *whalebone* and *box, cut acroſs their fibres*, increaſed very nearly in proportion to the quantity of moiſture, and more ſo than any other ſubſtances which he tried. He, however, preferred the *whalebone;* 1ſt. on account of it's ſteadineſs, in always coming to the ſame point at extreme moiſture; 2dly. on account of it's greater expanſion, increaſing in length above one eighth of it's length, from extreme dryneſs to extreme moiſture; laſtly, becauſe it is more eaſily made thin and narrow.

As the whole atmoſpheric œconomy, as far, at leaſt, as relates to the weather, depends upon, or is connected with the ſtate of the vapour it contains, it is rather ſurprizing that we find ſo few hygrometrical obſervations among the many meteorological diaries that have been publiſhed. From time immemorial, the effects of moiſture have been conſidered as prognoſtic of the weather, as is evident by the confidence the houſewife places in her ſalt-box, the carter in his whit-leather thong, and the ſailor in his ſhrouds.

But whether the hygrometer be a prognoſtic or not of the weather, it is certainly of the utmoſt importance to the natural philoſopher, and would probably prove a valuable oracle to the farmer, which is fully evinced by the following obſervation of Mr. Marſhall, in his minutes of agriculture. "Yeſterday morning, (ſays he) while the hygrometer ſtood at 2 degrees moiſt, the peas were by no means fit for carrying; the halm was green, and the peas ſoft. About ten o'clock the hygrometer fell to 1 degree dry; before one the peas were in

good order; I went up into the field, merely on the WORD of the hygrometer, and found the peas fit to be carried." It is plain, therefore, that on a ſcattered farm, in hay-time and harveſt, an hygrometer muſt be peculiarly uſeful.

Before I proceed to take further notice of hygrometers, it will be neceſſary to remind you of the principles I have already laid down concerning evaporation and vapour; for, unleſs theſe are properly attended to, you will never be able to attain any fixed and certain notions of meteorology.—Atmoſpherical fluids are diviſible into two claſſes, *vapours* and *aeriform*, the diſtinctive characters of which are theſe: *vapours* are decompoſed by *preſſure*, but *aeriform* fluids bear the ſtrongeſt compreſſion without decompoſition: *vapours* are decompoſed in *veſſels hermetically ſealed*, by the ſpontaneous eſcape of fire; but *aeriform* fluids can only be decompoſed by ſome ſubſtance, to which their gravitating matter has more affinity than to the fluid which maintains them in an *aeriform* ſtate. In *vapours* the proportions of the component parts are very variable, according to the ſubſiſting circumſtances; but *aeriform* fluids, when once formed, continue in the ſame ſtate, and can only be changed by *chemical* cauſes: the difference ariſes from the weakneſs of the union of water in vapour with fire, ſo that it can ſeparate itſelf therefrom by the mutual tendency of it's own particles, when they are brought within a certain diſtance one of the other, and becauſe fire can ſo eaſily quit them, to reſtore certain equilibria with reſpect to itſelf.

By watery vapour, I do not here mean *viſible opake ſteam or vapour*, becauſe that is *vapour in a ſtate of decompoſition*; I mean the *inviſible* and *tranſparent exhalations*, which conſtitute a *peculiar* and *diſtinct fluid*, expanſible and compreſſible, and ſo

I far

far poſſeſſing the mechanical properties of *aeriform* fluids, and exerciſing theſe properties whether mixed with them or alone.

The *ſpecific gravity* of theſe vapours is above *one half leſs* than that of common air; that is; when they exerciſe a certain expanſive force, whether alone or mixed with air, their *maſs* is above one half leſs than a like volume of *air*, which would exerciſe the ſame expanſive force.

In the courſe of our Lectures on fire, I ſhewed you that vapour conſiſts of particles of fire, united with thoſe of water, and that there was no foundation for the hypotheſis which conſidered it as *a chemical ſolution of water by air.* This is, however, an hypotheſis that has been adopted by ſo many writers, though contrary to every circumſtance duly examined, and of ſuch conſequence in meteorology, that I ſhall again make a few remarks thereon. I ſhall firſt notice the phenomena of air contained in water, and ſhew you that theſe have no relation to the common notions of ſolution. If water be placed in a receiver, and a *vacuum* made, a number of air-bubbles are formed in the midſt of the water, which increaſe in ſize, and then eſcape. Now, there is no principle in the theory of diſſolution, which can explain, why a menſtruum, becauſe it is leſs preſſed, ſhould let go the ſubſtance that it had diſſolved; whereas it ſhould hold it ſtronger if the menſtruum is thereby dilated. When the water ceaſes to produce air by this operation, if you *agitate* it ſtrongly, more air is diſengaged; this alſo is contrary to the theory of diſſolution, for this is promoted by the agitation of the menſtruum. When both theſe methods ceaſe to be efficacious, more air may be diſengaged by *heat;* here the hypotheſis is contradicted at it's very foundation; the ſole plauſibility on which it reſted, was derived from the idea that the air could contain more

more water when it's heat was greateſt, which of courſe muſt alſo take place with reſpect to air contained in water, to which you ſee this fact is diametrically oppoſed. I have ſhewn you in the Lecture on fire, that the phenomena of aqueous vapour are the ſame *in vacuo* as in *open air*, that it may be produced *in vacuo*, without any concurrence of the air. The denſity of the vapour is the ſame every where at any temperature, provided the particles thereof keep at a certain diſtance from each other. This denſity in every ſpace, and at every temperature, is determined by a certain minimum diſtance among the particles of the vapour. It is ſufficient for their conſervation as vapour, either in *vacuo* or in *air*, that they are not forced to approach within this diſtance. The product of evaporation is always of this nature, namely, an expanſible fluid, which either alone or in air affects the manometer by preſſure, and the hygrometer by moiſture, without any difference ariſing from the preſence or abſence of air. I may again, therefore, repeat after M. de Luc, *that every phenomenon proves that the hypotheſis of the ſolution of water by air is vague, without any ſolid foundation, unneceſſary for the explanation of evaporation, while it involves every branch of philoſophy in obſcurity.**

Evaporation is *a diſſolution of water by fire.* A moſt deciſive reaſon in ſupport of this opinion is, that every liquid cools when it evaporates; the portion of the liquid that diſappears, being carried away by a quantity of *fire* proceeding from the liquid itſelf. Mr. Watt has ſhewn, that in the common evaporation of water in open air, the quantity

* See Mr. de Luc's Letters, dans le Journal de Phyſique, his Idees ſur la Meteorologie.

See alſo further proofs of the errors of the chemical idea of water being ſolved by air, in Vol. 2. Lecture 13, p. 76 and 77.

quantity of heat loſt by the maſs, bears to the quantity of water carried away, a proportion ſtill greater than that which is found in the ſteam produced by boiling water.

As *vapour* conſiſts of fire and water united, and forming a new compound, the *ſpecific properties* of each of the component parts are in certain reſpects ſuppreſſed, as in other chemical operations, the water loſes it's faculty of moiſtening, and the fire that of producing heat; hence the loſs of heat in the evaporation of liquids, and the augmentation of heat in the decompoſition of vapour. The particles both of fire and water ſtill, however, retain the faculty of maintaining their reſpective equilibrium between the medium and ſurrounding bodies. Thus the particles of water ſtill retain the tendency of uniting together, and this union takes place whenever they are ſo near each other, that this tendency can ſurmount the effort of the fire, which keeps them diſſeminated.

Of courſe, the leſs the quantity of free fire (or the cauſe of heat) in a given ſpace, the greater is the diſtance at which the particles of water can exert their faculty of uniting together, and of abandoning their latent fire. The precipitation of water or final union, therefore, takes place when the denſity of vapour has exceeded certain limits, which limits depend on the temperature; for the greater the quantity of free fire in a given ſpace, the nearer the particles of vapour may approach each other without being decompoſed, that is, without the watery particles, in conſequence of their natural tendency, reuniting together, and quitting the fire with which they were aſſociated.

Thus there is neceſſarily a minimum of diſtance of the aqueous particles, beyond which the vapour cannot be compreſſed without being decompoſed; and this is different in different degrees

of

of heat, but conſtant in the ſame. When vapour is mixed with air, they can ſuſtain a much greater preſſure than they can by themſelves, becauſe the air ſupports the preſſure, and prevents the particles from being forced within their minimum diſtance; and it is thus that vapours ſubſiſt in the atmoſphere, without being decompoſed by it's preſſure.

Vapours are decompoſed not only by the mutual approach of the particles, but alſo in virtue of the affinity of water to thoſe ſubſtances that are called *hygroſcopic*, of which *fire* may be reckoned one. The principal law of this affinity is, that the water diſtributes itſelf to all the ſubſtances of the claſs that are within it's reach, to every one alike, proportional to it's capacity of retention. If new *fire be introduced* into a given ſpace, where there is no ſuperabundant water, it will *take away* ſome of the water from all the hygroſcopic ſubſtances, and *diminiſh their humidity*. If ſome of the *fire be taken away*, the water that was united thereto, will be divided among all the reſt; and if any other hygroſcopic ſubſtances be introduced, containing a greater or leſs quantity of humidity than thoſe already there, the ſurplus of humidity will be divided among them. It is *by fire* that this diſtribution is effected; the particles of this element *being always in motion*, take up the water from one that has more than it's ſhare, and give it out to another that has leſs. Thus hygroſcopic ſubſtances have their humidity always proportional to the places they are in.

Hygroſcopic ſubſtances are of three diſtinct claſſes: 1ſt. Thoſe that ſeize on the water of vapour, by a chemical affinity with that liquid; among theſe are acids, ſalts, and calces. 2d. Thoſe that imbibe the water, by the tendency it has to propagate itſelf in capillary pores, but from their nature receive no ſenſible increaſe of bulk by it's introduction;

introduction; ſuch are porous ſtones. 3d. Thoſe that, imbibing a certain quantity of water, are thereby expanded; and theſe are moſt of the ſolids of the vegetable and animal kingdoms. Mr. de Luc, by a long ſeries of experiments, to which I muſt refer you, ſhews, that the ſubſtances of the laſt claſs are the only ones proper for hygrometers, and that even in this claſs, to avoid fallacy, in reſpect to the moſt important phenomena, we muſt uſe thoſe that ceaſe to lengthen, only when they cannot be penetrated with more water.

Here, however, it will be neceſſary to define in what ſenſe we uſe the words *moiſture* and *humidity*, for in the manner they are commonly uſed, they ſometimes imply a cauſe, ſometimes an effect; this ambiguity is not peculiar to theſe words, you will find many others uſed in philoſophy as ambiguous, particularly when they have been applied to certain phenomena, the cauſes of which are not determined.

Moisture, *in a general ſenſe, may be conſidered as inviſible water, producing obſervable phenomena.*

Thus in *hygroſcopic bodies*, the quantity of water which expands them, and increaſes their weight, is concealed within their pores; and in the *ambient medium*, that water which affects hygroſcopic bodies, being there under the form of vapour, is as *inviſible* as the air itſelf.

But in reſpect to *hygrometry*, where *moiſture* is conſidered as having correſpondent degrees in the medium, the word requires a more particular determination. *Moiſture* may be either totally abſent or abſolutely extreme, both in the hygroſcopic bodies and in the ambient medium; hence, both in the whole and in correſpondent parts, moiſture aſſumes in the *medium* the character of a *cauſe*,

caufe, and in *hygrofcopic bodies* that of an effect. Thefe two circumftances furnifh us alfo with a fixed module for determining correfpondent degrees.

Moifture is totally abfent, firft, in the medium when it contains no vapour, and then as a confequence in hygrofcopic bodies, becaufe they contain no more water that can evaporate, without a decompofition of their component parts. The cafe here fuppofed is, that when, by fome adequate caufe, no fenfible quantity of vapour is permitted to remain in the medium, as in the lime veffel ufed by Mr. de Luc to obtain the point of extreme drynefs.

Moifture is extreme, firft, in the medium, whether air or a fpace free from air, when no more vapour can be introduced therein, without a part being decompofed; and then, as a confequence in hygrofcopic bodies, becaufe no more water can be admitted in their pores.

Here it is to be obferved, that from the nature of the laft of thefe maxima the quantity of water which produces it (i. e. extreme moifture) in a given body is *fixed*, becaufe it is determined by the actual capacity of it's pores; but the quantity of water which produces extreme moifture in a medium of a given extent is as *variable* as the temperature.

The equilibrium therefore between the medium and hygrofcopic bodies in different ftages of moifture, which equilibrium is the object of hygrometry as a fcience, does not depend on *certain quantities of water* contained in the medium of which bodies may receive their fhare; it depends on different *aptitudes* of the vapour contained in the medium to communicate water to thofe bodies; which aptitudes vary not only with the different

denfities

densities of that fluid, but also in vapour of the same density according to the temperature.*

From the *hygrometer* we have learnt, that in the phenomenon of *dew* the *grass* often begins to be *wet*, when the *air* a little above it is still in a middle state of *moisture*; and that *extreme moisture* is only certain in that *air*, when every solid exposed thereto is *wet*. It has taught us, that the *maximum* of *evaporation* in a close space, is far from being identical with the *maximum* of *moisture*; this depending considerably, though with the constant existence of the other, on the *temperature* common to the *space* and the *water* that evaporates. It has shewn, that the case of *extreme moisture* existing in the open transparent air, in the day, even when it *rains*, is extremely rare: Mr. de Luc has only found it once in this state, the *temperature* being 39°. Messrs. de Saussure and de Luc have proved by the hygrometer, that the *air* is *dryer* and *dryer* as we ascend in the atmosphere, so that in the upper attainable regions, it is constantly very *dry*, except in the *clouds*. Mr. de Saussure has shewn, that if the whole atmosphere passed from *extreme dryness* to extreme *moisture*, the quantity of water thus *evaporated* would not raise the *barometer* half an inch. Lastly, in chemical operations on the *air*, the greatest quantity of *evaporated water* that may be supposed in them, at the common *temperature* of the atmosphere, even if they were at *extreme moisture*, is not so much as the one hundredth part of their mass. The two last very important propositions have been demonstrated by *M. de Saussure*.†

LECTURE.

* See Mr. de Luc's paper on Evaporation, from which the remarks on Hygrometers, &c. is an extract, Phil. Trans. for 1791, part 9.

† See Mr. de Luc's second paper on Hygrometry, Phil. Trans.

LECTURE LII.

Of Rain.

IN a ſcience ſo very difficult as that of the weather, it is not to be ſuppoſed that any thing like a certain and eſtabliſhed theory can be laid down: our utmoſt knowledge in this reſpect goes no further as yet than the eſtabliſhment of a few facts; and in reaſoning upon theſe, we are involved every moment in queſtions which ſeem ſcarcely within the compaſs of human wiſdom to reſolve.

To treat it in a ſatisfactory manner, we ought to have an intimate acquaintance with the conſtitution of the atmoſphere, and the nature of thoſe powerful agents, fire, light, and electricity, by which it ſeems to be principally influenced; with their peculiar influences upon one another, and upon the atmoſphere, and this in every poſſible variety of circumſtances. Many of the qualities of air, earth, water, and fire, have been indeed diſcovered and eſtimated; but when theſe come to be united by nature, they often produce a reſult which no artificial combinations can imitate. Every cloud that moves, and every ſhower that falls, ſerves to mortify the philoſopher, and to ſhew him hidden qualities in air and water that he is unable to explain.

The greater part of the received notions on meteorology are vague and incorrect, not only thoſe which relate to the nature of the cauſes, but thoſe alſo which concern the laws of their effects. The ſame may be ſaid of our notions of the *elaſticity* of the *air*, of *heat* when applied to this fluid, of both igneous and aqueous meteors, of ſudden and partial

partial winds; they are all ſo many enigmas to the philoſopher.

Indeed, till we were in poſſeſſion of a good *hygrometer*, it was impoſſible to form any certain concluſions concerning the moiſture of the air: this difficulty is removed; Mr. de Luc has by numerous experiments and obſervations furniſhed us with a comparative *hygrometer*, by which together with a thermometer the air can neither loſe nor acquire *moiſture* without our being advertiſed thereof.

By the uſe of this hygrometer we have obtained clear and certain ideas of the cauſes, by which *water, ſimply evaporated* in air, may be *precipitated* therefrom. Theſe cauſes are the ſame with thoſe, which, in *air* where the quantity of evaporated water remains the ſame, always produce an increaſe of *moiſture*, the neceſſary forerunner of the precipitation of water; and theſe are two; the *compreſſion* of the air, or it's being *cooled*: no other cauſes are indicated by experiment. Some philoſophers have thought that the air, when rarified, quitted a portion of the water which, according to them, it held in ſolution; but I have ſhewn you, that this idea is erroneous, and that rarifaction occaſioned dryneſs inſtead of moiſture.

The great queſtion therefore in the inquiry concerning the immediate cauſe of clouds, &c. is, What becomes of the water that riſes as vapour into the atmoſphere? What is the ſtate in which it ſubſiſts there between the time of it's evaporation and the time of it's falling down again in rain?

If it continues in a ſtate of *watery vapour*, or ſuch as is the immediate product of evaporation, it muſt poſſeſs the diſtinctive characters eſſential to that fluid. It muſt make the hygrometer move towards humidity in proportion as the vapour is

more or lefs abundant in the air. On a diminution of heat, the moifture, as fhewn by the hygrometer, would increafe; but on an increafe of heat, the humidity would decreafe. Again, on this fuppofition, if hygrofcopic fubftances dryer than the air be introduced therein, they muft have the fame effect as an augmentation of heat: for fuch are always the properties of aqueous vapour on every hypothefis of evaporation. If therefore *water* exifts in the atmofphere, without thefe properties, *it is no longer vapour, it muft have changed it's nature.* Mr. de Luc has fhewn, that the water which forms rain, does not poffefs thefe properties; it muft therefore have *paffed into another ftate.*

Repeated obfervations have fhewn, that the *upper regions* of the atmofphere, notwithftanding the continual afcent of vapours there, are *dryer* than the inferior regions; on the fummits of high mountains a degree of drynefs prevails, unknown on the plains.

If *rain* be the *immediate product of evaporation,* it ought always to be preceded and accompanied by a diminution of heat, in that ftratum of air where it originated; and this diminution, to produce it's effect, fhould be greater in proportion as the moifture was further removed from it's extreme term in this ftratum; but in a great ftorm on the mountain of *Sixt,* Mr. de Luc found that the heat had increafed inftead of diminifhed; this caufe could not operate here, and it was therefore impoffible that the quantity of *water* which was then *precipitated* from the air could have been contained there in the form of the *immediate product of evaporation.*

On every hypothefis of the formation of rain from *vapour,* it is *heat* that produces the evaporation, and a *diminution of heat* that occafions the

return

return of vapour into water, and therefore rain ſhould happen only in the *night*, or at the coldeſt time of the day; whereas experience ſhews, that it has no connection with heat or cold. We have rain as often in the *day* time, when, according to the natural courſe of things, the heat of the atmoſphere ſhould be the greateſt, as at *night* when the heat ought to diminiſh; beſides, the heat often diminiſhes in the day without producing rain. Whatever be the degree of heat, the air can only part with ſo much of it's water, as it is unable to retain in that degree of heat; *no rain* ſhould therefore be formed, unleſs the air was ſaturated, or at *extreme moiſture*; but this alſo is contrary to fact.

Thus when Mr. de Luc and his brother were on the *Sixt*, though the hygrometer was $66\frac{1}{2}$ degrees from extreme humidity, thick clouds formed around them, which obliged them to think of retreating; in a little time the ſummit of the mountain was ſurrounded by them, they ſpread and covered the whole horizon, a premature night ſurprized them in a very dangerous road, and a moſt violent ſtorm of wind, rain, hail, and thunder, laſted the greater part of the night; it extended over all the neighbouring mountains and plains; after the ſtorm ceaſed, the rain continued with very few intermiſſions till the next day at noon. The hygrometer being examined in one of theſe intervals, only ſhewed $1\frac{6}{10}$ more moiſture than before; and even this increaſe was no other than what the difference of heat was ſufficient for producing; nevertheleſs new clouds were formed, and the rain began again, accompanying our travellers by fits to the bottom of the mountain; when arrived there, the clouds entirely diſperſed, the hygrometer was again obſerved in the open air, and though the earth was drenched with water, and the heat much leſs, the

hygrometer was $1\frac{1}{10}$ *dryer* than it had been two days before, after a courſe of fine weather. Now *where* was all this water, and all the ingredients of the ſtorm, while the hygrometer ſhewed ſuch a degree of *dryneſs* in the ſtratum where it was formed?

The reaſoning of Mr. de Luc is confirmed by the phenomena of *fair weather*; continued evaporation from the inexhauſtible ſource of vapour the ocean, and from the earth after it has been ſoaked with rain, would, if vapour did not *change it's nature* in the atmoſphere, render it more and more humid, and bring it at laſt to a maximum of humidity, as it does under a glaſs receiver. But experience ſhews, that though the evaporation continues for ſeveral months together on vaſt extents both of ſeas and continents, the air does not become moiſter, but on the contrary more and more *dry*. The diminution of heat in the night produces *dew*; but this ſymptom of humidity diminiſhes from day to day, and ſometimes ceaſes altogether.

Many attribute the ordinary occurrences of rain to changes in the *winds*. When it rains with a *ſouth wind*, it is ſuppoſed that theſe winds are warm becauſe they come from the ſouth, and that they are more humid becauſe the greater heats in thoſe climates from which they proceed, ought to produce a greater degree of evaporation, and that conſequently when this air meets with a colder part of the atmoſphere, the water it contained would be precipitated. If it rains by a *north wind*, it is imagined that this wind being colder than our air, produces the ſame effect that this did upon the ſouth wind. There are however various reaſons which prove, that theſe winds are not the immediate cauſe of the phenomena.

To place this hypotheſis in the moſt favourable light, we will ſuppoſe that one ſtratum of air is

is at reſt and the other in motion, and that both are *ſaturated* with the immediate product of evaporation. But the quantity of evaporated water, which conſtitutes ſaturation or a maximum of humidity in the air, varies with the temperature, augmenting or diminiſhing with the heat. The colder air will therefore contain proportionally leſs evaporated water than the other. When theſe two airs meet, the one will be cooled, which ſhould produce a precipitation of water; but the other will at the ſame time be as much heated, and therefore capable of receiving the ſuperfluous water: at firſt a *miſt* may be formed, but this will not be durable; for as it is in contact with the air that is growing warmer, it is ſoon diſſipated.

It ſometimes rains with a ſouth wind, which ſeems to embrace the whole height of the atmoſphere; here it has been gratuitouſly ſuppoſed, that this air proceeded from the torrid zone, ſaturated with water throughout it's whole height. Granting this ſuppoſition, it will not account for the phenomena of rain. I ſhall not conſider here the difference in the ſeaſons, which ought neceſſarily to influence theſe phenomena, which however is not perceived; for we have often durable rains with this wind in ſummer, when the change of climate will occaſion little or no variation in it's temperature. Whatever change the heat of this air undergoes, it will gradually take place on account of the viciſſitudes of day and night; for as ſoon as the rays of the ſun ceaſe to act upon our horizon, the heat in the air decreaſes in as great a degree as that in which it exiſted at the ſame hour of the day. If the air is thus cooled beyond a certain point, the exceſs is precipitated in *dew*: beſides, moiſture in the atmoſphere is daily deſtroyed by ſome cauſe of which we are ignorant, and re-appears as ſuddenly in vaſt abundance in ſome ſtrata by

caufes of which we are equally ignorant. If you confider attentively the confequences of all thefe facts, you will fee that there is very little probability that air, which travels night and day to come to us; and which muft neceffarily conform, and that fucceffively, in all the intermediate latitudes, to the various caufes that determine their mean degrees of humidity and heat, can ever occafion the phenomena attributed thereto.

The remarks I have juft made on the effect fuppofed to be deducible from different winds, are formed from the notions we gain by obfervations made in plains. They are confirmed and ftrengthened when connected with obfervations made on mountains, for there thefe winds are found without thofe deceiving appearances which favour the hypothefis we are combating; they are found to convey *cold* there, while they are communicating *heat* to the plains below. Now if the *fouth* wind derives it's heat from the climate whence it proceeded, why is it not warm on the tops of mountains as well as in the plains? If it be faid, that it is cold alfo on the tops of high mountains in the torrid zone, we reply, that if fo, this in itfelf is a great myftery; and further, that no one can fuppofe that the fuperior air of this zone preferves it's pofition and degree during it's whole paffage, and arrives in the fame ftate at the tops of the northern mountains; and we may conclude, that, though the air which proceeds from climates warmer than our's, be then hotter than the air furrounding us, yet, the greateft heat we find therein does not in general proceed from this caufe, but from fome difference in it's nature, whereby the *folar rays* are rendered more powerful and more capable of producing heat near the furface of the earth.

From obfervations that have been made on mountains, we may draw the fame conclufions with refpect

respect to the *humidity* that generally accompanies *south winds* near the earth. For from these we find, that they do not produce the same effects in the higher region of the atmosphere, but accord with the usual *dryness* of these superior strata; they are not therefore in themselves the immediate causes of these differences; for if this were the case, the higher regions would be as much affected as the lower, or they could not be considered as an assemblage of the same fluids. But in this *assemblage* there may be unknown *fluids*, on which the *solar rays* may in the lower regions have a different influence, arising from circumstances of which we are ignorant, perhaps from a greater or less density in the mass, or from a difference in their distance from the soil of the earth. Every circumstance seems to indicate, that *chemical operations* are the general cause of the phenomena, though in a manner unknown; among the agents concerned, the *solar rays* hold the first rank.

The necessity of the solar rays for the fructification of vegetables, has been long established; Messrs. Priestley, Ingenhouz, and Sennebier, have proved, that this operation is accompanied by great modifications in the *air*, modifications which are essentially altered by the presence or absence of the *solar rays*. By these operations we see new *solids* rising before us; and yet, if we are scrupulous in the connection of causes with effects, we must confess our inability of tracing here the *combinations* of this first *substance*, which evidently puts in action every substance on our globe. We know in this instance, that some of the substances belong to the atmosphere, some to the earth, and that both are modified by the solar rays: *fire* also participates, but *light* is a constituent part of fire: *water* has it's share, but water contains *fire* and *light*: some ingredients of *air* are joined thereto, but of these

ingredients, thoſe that are united depend on the quantity of *light*. Thus, however, new *compounds* are formed, poſſeſſed of different colours, conſiſtency, odour, flavour, and chemical properties. All theſe wonderful operations are produced by the medium of the ſolar rays from the atmoſphere and from the earth ; and theſe modifications taking place on the earth and on the waters, over the whole ſurface of the globe, muſt be conſidered as a claſs of cauſes which have conſiderable influence in *meteorology*.

OF THE NATURE OF CLOUDS.

From conſidering the cauſes of rain, I proceed to inveſtigate the nature of clouds. As it is from theſe that rain proceeds, we muſt acknowledge the bleſſings we receive through them, though we are not able to account for their various phenomena. They are continually travelling over our globe, and by a proper diſtribution of moiſture, rendering the ſpacious paſtures of the wealthy fruitful, and gladdening the little ſpot of the cottager. *They ſatisfy the deſolate and waſte ground, and cauſe the bud of the tender herb to ſpring forth* ; that the natives of the lonely deſert, the herds which know no maſter's ſtalls, may nevertheleſs experience the care of an ALL-SUPPORTING PARENT.

Clouds are compoſed of a maſs of *veſicles* like ſoap bubbles, which veſicles are eaſily perceived in proper ſituations, particularly on high mountains : theſe veſicles float in the air, riſing or falling, till they are in equilibrium with the air, remaining ſuſpended there as long as they preſerve the ſame ſtate. By the nature of the ſuſpenſion of theſe aqueous veſicles, they do not alter the preſſure exerciſed by the ſtrata in which they are incloſed, neither on itſelf nor on the inferior ſtrata.

When

When the particles of vapour, properly fo called, approach within a certain diftance of each other, which is determined by the actual quantity of *free fire*, the particles of water, of which they are compofed, tend to unite, and the fire which quits them joins itfelf to the remaining particles of vapour. From the obfervation of Mr. de Luc it appears, that veficles of liquid water may be formed, and exift when the temperature of the air is at freezing. I have already fhewn you, that there is fomething elfe befides cold, neceffary to the formation of ice. It is hence we fee mifts, fogs, and clouds, when the thermometer is under 32°. There is never, however, any great cold in fogs or in clouds, for the caufe, whatever it may be, that brings vapour beyond it's maximum, diffeminates alfo heat. Aqueous veficles never freeze without changing their ftate; but if the bubbles are broken when the air is at or under 32 degrees, the water thereof freezes: if this happens in the midft of clouds, fnow is the confequence, whofe duration, like that of rain, depends on the quantity of veficles that are brought within a certain diftance of each other; the deftroyed veficles then group themfelves into flakes of fnow, by a *cryftallization*, fomewhat fimilar to what are termed by chemifts *fublimations*, i. e. the *precipitations* of fubftances diffolved by *fire*. If the quantity of aqueous veficles is too fmall to unite and be deftroyed, by being brought near together, they may be deftroyed and frozen by caufes fimilar to thofe which fix fublimates to the fides of the furnace and other receivers, or which determine congelation in water fufficiently cooled. In this cafe a hoar froft is formed.

Clouds are always compofed of bubbles, formed of liquid water, and they are generally at a temperature very little above the freezing point; the exiftence

exiſtence of theſe veſicles or bubbles is but of ſhort duration, they riſe and are deſtroyed ſucceſſively, like the brilliant ſparks we often perceive riſing from a chafing diſh, when the coals are animated by a bellows.

OF THE DURATION OF CLOUDS.

Whenever we ſee a miſt or a fog, formed by a known cauſe, we are always certain that the vapours, from which it proceeds, are paſſing rapidly beyond their maximum; and the miſt ceaſes when no freſh vapour arrives for it's ſupport. The principal known cauſes of miſts and fogs are either the ebullition of water in open air at all temperatures, the tranſpiration and reſpiration of animals in winter, the evaporation from hot ſprings in the ſame ſeaſons, and the fogs, properly ſo called, that happen in autumn. In all theſe caſes, we know that the vapour is produced in too great abundance for the temperature of the neighbouring air; hence a rapid deſtruction of a part of thoſe which arrive in that ſpace which is occupied by the fog. Meanwhile, the fog only occupies a certain ſpace, which is nearly fixed as long as the circumſtances remain the ſame; in a word, we always find fog and miſts to ceaſe, as ſoon as the cauſe producing the vapours ceaſes to furniſh them beyond the maximum ſuitable to the temperature of the air; the veſicles are formed by a rapid decompoſition of ſuperfluous vapours; as ſoon as this ceaſes, the veſicles are diſſipated.

From a review of known facts, you will find that the following concluſions are well founded. 1ſt. That veſicles are only formed in thoſe caſes where vapours get beyond their maximum. 2d. That theſe veſicles are *concrete water*, ſubject to *evaporation*, like any other water, and which always

always evaporate when the furrounding air is not at the *extreme point of humidity.* 3d. It is this laft mentioned circumftance, which determines the extent of fpace occupied by a cloud or fog; for thefe vefícles only exift in that part, where the fource of vapours, whatever it may be, having produced *extreme humidity,* diffeminates fuperfluous vapour; fo that beyond this fpace, the vefícles evaporate. 4th, and laftly, This evaporation is prevented in whole or in part, either by obftacles that oppofe the expanfion of the mift or fog, or becaufe the fource of vapours furnifhes them fo rapidly that the vefícles approach near enough to unite even in the midft of the fog, which occafions them to unite, and the refult is a diftillation of water. From hence we may conclude, that when a *cloud* is formed in air, whatever be the caufe, it can only fubfift there while aqueous vapours continue to be produced in the fame place. Thus, the extent occupied by a *cloud,* is an indication of the caufe which produces vapours, or of it's intenfity in fome part of this fpace: extreme humidity exifts but very little beyond the extent of the *cloud,* and, as foon as the caufe which furnifhes the vapour ceafes, the cloud diffipates.

We have been accuftomed to fee *clouds* from our earlieft infancy; they, therefore, neither excite attention, nor awaken admiration, and yet, of all the objects which furround us, there is none more truly wonderful, or more worthy of attention. Thofe alfo, who have but little ftudied the laws of hygrology, are very little aftonifhed at thefe appearances, becaufe they either fuffer themfelves to be amufed by words, or reft fatisfied with a few feducing glimpfes: thofe who have confidered the laws of hygrology, and weighed all the circumftances, find they are only carried to the boundaries of known caufes; but they alfo know how to ftop and

and wait there, till fresh light enables them to proceed further.

The traveller, who has frequented high mountains, knows, that clouds are a species of *fog* or *mist*, much resembling those we perceive on plains; he has also remarked, that where *clouds* are scattered in the air, the strata where they are met with, are not at extreme humidity. Among other instances, Mr. de Luc mentions one, where he saw his own shadow, and that of the rock on which he was situated, projected on a cloud beneath him, in a stratum where there were many other similar clouds extending to a considerable distance. The air was very serene, and there was not the least *symptom of extreme humidity*. How are such clouds preserved? Whence do they increase to the eye? Why, as they are continually evaporating, are they not immediately dissipated?

The *evaporation* of clouds, even while they are increasing in size, is a circumstance of which you may easily be satisfied, by considering attentively the broken edge of a cloud, which has an azure ground behind it. These edges present to the imagination a thousand grotesque forms, which, by their striking changes, will assist you in your researches. Often you may perceive the part which you are looking at, dissipated in the place where it was first observed: often it stretches itself out, the cloud remaining stationary, and vanishes while it is thus extending itself. Sometimes while one festoon vanishes, others are formed, by which the cloud is enlarged; at other times it diminishes, the festoons successively evaporating, till the whole disappears. It is impossible to consider these various metamorphoses of the same cloud, without supposing that there is in the air a source of *vapours*, which are produced in the place where the cloud is formed, and that it is by the continued

tinued production of *fresh vapour* that the cloud subsists and increases, though continually evaporating. When they wholly disappear, it is because the evaporation is not repaired by the formation of fresh vapour. These phenomena are independent of *heat* and *cold*, for clouds are sometimes formed suddenly in the midst of a *hot day*, and after they have poured down their water, all is clear again. Sometimes they evaporate after sun-set, gradually vanishing in the calmest weather, without change of place. The appearances, on the whole, are such as would be produced by a large mass of water in violent ebullition, suspended invisibly in the atmosphere; and the similarity in the effect naturally points out an analogy in the cause, that is, *a source of vapour in the atmosphere.*

When it rains, the source which furnishes vapours produces them in such abundance, that the vesicles which are formed are driven against each other even in the bosom of the cloud; and not having time either to disperse or evaporate, they are united; and the water falling to the lowest part, as in soap-bubbles, they are soon burst, and fall as rain. It is to these surcharged vesicles we must attribute the pendent fringes which are sometimes seen under the clouds towards the horizon. Experience has shewn, that it rains under those clouds; not that these fringes are rain itself, but the vesicles which fall by the augmentation of their weight. As drops of rain are formed, the vesicles are destroyed.

Lasting rains proceed from strata of *clouds* which cover the whole heavens; and it is these that have the greatest connection with the fall of the mercury in the barometer. The source of vapours comprehending a stratum of considerable extent, the barometer, after it has announced these rains, generally rises, and continues to rise, as long as they last.

laſt. This is a fact often obſerved, but to us inexplicable. It is no doubt connected in ſome way with the primitive cauſe of rain, but with that cauſe we are unacquainted. The relation of rain with the barometer, is a ſubject as obſcure as the cauſe of rain itſelf.

In the midſt ſometimes of the fineſt days, and while ordinary ſymptoms indicate that the air is *dry*, and this as well in the vallies as on the mountains, bright heavy clouds appear on an azure ground, announcing ſudden rains. Sometimes theſe clouds increaſe enormouſly, and deſcend; other clouds form about, and unite to them; the air is darkened, as if a curtain was drawn between heaven and earth. From the tops of high mountains, theſe clouds may be often ſeen to accumulate rapidly over the plains; while from theſe the azure ground of the heavens diſappears, the wind often riſes, and blows from different quarters in a kind of whirlwind, and laſtly it pours with rain. As ſoon as the rain ceaſes, the curtain is withdrawn, the calm is reſtored, the ſun re-appears, and no other veſtiges remain of this grand phenomenon but the water that is on the ground.

When the air is diſpoſed to produce this phenomenon, you will often ſee the *clouds* riſing from the horizon; ſometimes from the ſide where the wind proceeds, ſometimes from other quarters. Often theſe heavy ſhowers are partial: ſometimes they re-commence at intervals, accompanied with heavy ſqualls. Sometimes theſe heavy intermitting ſhowers are a prelude of more laſting rains; in which caſe the clouds unite, the wind goes down, and you have one or more ſucceſſive days of rain.

OF

Of Hail.

Sudden ftorms, accompanied with *hail* and *thunder*, are among the number of phenomena which fhew how ignorant we are of the caufes of thofe that we obferve in the atmofphere. *Hail* is a fign of a great degree of *cold*; but what is the immediate caufe thereof? Whence a fubftance, that muft require fo intenfe a cold for it's formation, in feafons fo warm as thofe in which hail is chiefly formed? It is fuppofed, in general, that hailftones are drops of rain, which, falling through a colder region of air, are congealed in their paffage into a rarified fort of ice. Dr. Halley gives an account of hailftones that *weighed five ounces each*, and fays, it is very extraordinary that fuch fort of vapours fhould continue undifperfed fo long a tract as fixty miles together; and in all the way of it's paffage, occafion fo extraordinary a coagulation and congelation in the watery clouds, as to increafe the hailftones to fo vaft a bulk in fo fhort a fpace as that of their fall.

Of Thunder.

All the phenomena of ftormy clouds are obfcure, and I am afraid there is very little probability of explaining them independent of each other. Thofe that are fatisfied with conjectures, may find enough at their fervice; but he who conducts himfelf by the "fcale and chart of truth," will find little to depend upon. It is thus with thunder and lightning: we can neither account for the immenfe quantities of electricity difcharged by the one, nor the rumbling noife of the other.

Mr. Volta fuppofed that water, by being changed into vapour, acquired a greater capacity for

for the electric fluid, and that thus electricity was continually conveyed to the atmosphere by *evaporation;* and this he deduced from an experiment, in which water being evaporated from a body, left that body negatively electrified. This, however, is by no means satisfactory; for, not to insist on the fallacy of the terms *positive* and *negative*, as both electricities may be produced by evaporation, if the electric fluid passed from the earth to the atmosphere by evaporation, and it's return was occasioned by the reduction of vapour into water, there would always be more or less lightning when there was violent and sudden rain, for in this case it would be rapidly disengaged; but there is much oftener violent and sudden rain without than with lightning. In this case lightning also should always be preceded by rain, whereas there is often lightning among the clouds without any rain. Further, if we are unable to explain rain by the vapours which existed in the air before the formation of the clouds, the source of electricity existing in clouds ought not to be sought for in vapour. Indeed, on this supposition, as soon as there was a violent rain the lightning would cease, and the fluid would pass off by the drops, illuminating the air by it's passage from drop to drop.

There seems to be no other mode of considering lightning, than as an *explosion*, that is, as a sudden production of a great quantity of the electric fluid; the fluid which is then manifested not existing as such but just before we perceive it's effects; just as the vapour, of which the clouds are formed, do not exist as vapour in the air until the moment of their appearance: the *air*, as yet *transparent*, contained neither the vapour of which the cloud is formed, nor the electric fluids, but the ingredients proper to give birth to both of them. By some cause, of which we are ignorant, clouds of a certain

a certain kind are formed. During the progreſs of their formation, and by fits, the electric fluid is produced in great abundance, and explodes every time it is thus produced. Obſervations made among mountains where clouds are formed, point out this to be the reſult of the phenomena.

In a ſtorm obſerved by Mr. de Luc on the *Buet*, he had an opportunity of obſerving this phenomenon with all it's modifications. The *air* of the ſtrata where he was ſituated was perfectly *tranſparent* and *dry*; the thermometer at 6 of Reaumur. Notwithſtanding this, clouds formed here and there: by degrees they augmented, then became united, embracing the ſummit of the *Buet*, and ſupporting themſelves againſt *Mont Blanc*, and the ſummits of the neighbouring mountains. Mr. de Luc and his companions were inundated with rain: though the clouds and the rain formed a complete conductor, communicating with the ground, yet there was a continuance of thunder for a conſiderable time, and often very violent. Other inſtances may be found in the works of Mr. de Sauſſure, of thunder-ſtorms where the clouds formed a conducting communication with the ground, and yet where the thunder ſucceeded without interruption.

The rumbling noiſe of thunder has been explained by a ſuppoſed analogy between the paſſage of lightning and the electric ſpark through the air. This explanation might have been admitted as plauſible, if the rumbling noiſe of thunder had grown weaker and weaker, as being a ſucceſſion of ſounds proceeding ſucceſſively from points more and more diſtant; whereas the ſound of thunder often increaſes, and gives us a diſtinct perception of it's proceeding from points which are nearer to us than thoſe from which it ſet out. It is ſome-

times intermingled with ſuch terrible claps, as deprive the hypotheſis of all probability; or other inconſiſtences therein might be pointed out. The rumbling and repeated echoes, &c. of thunder, ſtill remain among the phenomena not yet accounted for.

In general, a courſe of hot weather precedes a thunder-ſtorm; and it ſeldom happens that very hot weather, in the ſummer, terminates without a ſtorm of thunder. Hence, alſo, in the Eaſt and Weſt Indies, where the climate is ſo much hotter, thunder and lightning are not only much more frequent, but much more violent, than in this country.

OF WINDS.

Of winds, the obſervation of our SAVIOUR is ſtill juſt: we hear the ſound of the wind as it paſſes by, but we neither know whence it comes, nor whither it goes; we cannot determine how it originates, or why it ceaſes. The great *Bacon*, indeed, was of opinion, that by a cloſe and regular hiſtory of the winds, continued for a number of ages together, and the particulars of each obſervation reduced to general maxims, we might at laſt come to underſtand the variations of this capricious element, and be able to foretel the certainty of a wind, with as much eaſe as we now foretel the return of an eclipſe. Indeed his own beginnings in this arduous taſk ſeem to ſpeak the poſſibility of it's ſucceſs; but unfortunately this inveſtigation is the work of ages, and we want a *Bacon* to direct the proceſs.

In the *Hiſtoria Ventorum*, Bacon reckons three ſources of winds; one by deſcent from the ſuperior regions of the atmoſphere, another from the expanſion of the lower air, and a third by exſpiration

ration from the earth: of which laſt he propoſes it as an object of inquiry, What winds blow out of ſubterraneous caverns? Whether they come forth in a large body, or blow inſenſibly here and there; and then unite in one ſtream, like a river formed out of many different ſprings? This latter cauſe has been but little attended to, though this reciprocation between the earth and air is ſurely a very intereſting part of natural philoſophy. In the language of holy writ, God is ſaid *to bring the winds out of his treaſures*; as if ſome hidden ſtorehouſe were alluded to, ſuch as that of the waters and cavities between the earth.

The annual revolution of the *ſun* is doubtleſs a general cauſe of winds; but this cauſe, conſidered alone, ſhould produce regular winds, whoſe progreſs would correſpond to, and be connected with the ſeaſons; but the phenomena obſerved by no means enable us to perceive this connection. There is another cauſe, of which we may form an imperfect idea, by which the winds proceeding from the ſouth, may be ſouth-weſt to us, and thoſe which come from the north, north-eaſt. This cauſe is the difference in the velocity of the motion of the parts of the earth we inhabit, and that at the equator, or the polar circles. If the air was *calm* at the equator, that is, moved with the ſame velocity as the earth, and that in coming from thence to us in the ſame direction, preſerving at the ſame time a portion of it's acquired motion, it would gain upon the earth in this direction, and would thus become ſouth-weſt. The ſame cauſe inverted would change the north for us into a north-eaſt wind. Another cauſe, though very inconſiderable, may be found in the different diurnal poſitions of the ſun: this, in calm weather, often occaſions a gentle eaſt wind after ſun-riſing, and a weſt wind after his ſetting.

Of these causes we have some knowledge; but there must be many, and more powerful ones, to produce those phenomena to which we are continual witnesses, and to which these seem to have little or no affinity. Evaporation and rain have been considered as causes; but they are also by no means adequate to the purpose. Evaporation is constantly operating; it is also more abundant in those places where the heat is greatest. These places are continually varying; but still the variations in evaporation are so slow, and the differences in heat so insensible from one place to another, that it can never occasion any sudden and violent wind. Rain, which is the inverse of evaporation, operates with more rapidity: but the same reasons which prove that rain cannot be formed of the immediate product of evaporation, also prove that the precipitation of this product, in any stratum of air, cannot make a sufficient vacuum to cause the surrounding air to press in with violence.

We must then have recourse to some other cause, to explain the winds which accompany the rapid formation and destruction of clouds; and this may be found in the return of air to a state of vapours. It is known from experiment, that in similar cases there is a great increase of volume in the new fluid; as in the sudden explosion of inflammable air with vital or common air. When the air is changed into aqueous vapour in the atmosphere, there is probably a considerable expansion of the stratum where this change happens, and the effect is more or less extensive in proportion to the strength of the cause. If the production of the clouds be slow, if it embraces a very great portion of the atmosphere, and if the operation be carried on at a great height, but little agitation will be perceived in the air under these strata: the columns thereof extending lengthwise, produce in

distant

diſtant countries *winds*, of which the inhabitants can no more perceive the cauſes, than thoſe near which it originated. But if the clouds are formed rapidly, if they occupy but a ſmall ſpace, and are not very high, violent winds may be occaſioned by the ſudden expanſion of the medium where they are formed. As the quantity of vapour that is the immediate product of evaporation is always very ſmall, the formation of drops of rain, on the common ſyſtem, would only produce inſenſible and trifling motions of the air. But in Mr. de Luc's ſyſtem, the ſucceſſive production of vapour in the midſt of the air is unlimited: their accumulation in the form of veſicles may be immenſe; and when they are reſolved into drops, a conſiderable vacuum is the natural conſequence.

From this view of the origin of winds, we may ſee alſo why, in a ſeaſon of ſtorms and ſhowers, a cold heavy cloud, paſſing over the head, with a haſty fall of ſnow or hail, is often attended with a ſudden violent guſt of wind, ſuch as ſailors call a ſquall, which ſubſides into a calm with the departure of the cloud; till another cloud, coming in the ſame direction, brings a freſh blaſt. No tempeſt, hurricane, or whirlwind, ever happens under a cloudleſs ſky. We hence may alſo perceive why a whiſtling or howling noiſe of the wind is the moſt infallible prognoſtic of rain, indicating the formation of rainy clouds. The ſacred ſcripture ſeems to agree with this; for the prophet Elijah, before any other ſymptom of the weather appeared, ſeemed to give notice to Ahab from this one: *Get thee up, and eat and drink*, ſaid he, *for there is a* SOUND *of abundance of rain*. Then it follows, *that the heaven was ſoon black with clouds and wind, and there was a great rain.*

OF TRADE-WINDS AND MONSOONS.

There are many parts of the world where the winds, that with us are ſo uncertain, pay their ſtated viſits. In ſome places, the winds are found to blow one way by day, another by night; in others, for one half of the year, they go in a direction contrary to their former courſe: but what is more extraordinary, there are ſome places where the winds never change, but for ever blow the ſame way. This is particularly found to obtain between the tropics, in the Atlantic ocean, and great Pacific ſea.

Between the limits of 60 degrees, namely, from 30° of north latitude to 30° of ſouth latitude, there is a conſtant eaſterly wind throughout the year, blowing on the Atlantic and Pacific oceans; and this is called the *trade-wind.*

The trade-winds near the northern limits blow between the north and the eaſt; and near the ſouthern limits, they blow between the ſouth and the eaſt.

Theſe general motions of the wind are diſturbed on the continent, and near the coaſts.

Beyond the northern limit of the general wind, on the Atlantic ocean, the weſterly winds prevail, but not with any certainty of continuance.

In the Atlantic ocean, the S. E. trade-wind extends as far as 3 degrees north; and the N. E. trade-wind ceaſes at the 5th degree N. In the intermediate ſpace are found calms with rain, and irregular uncertain ſqualls attended with thunder and lightning: but this ſpace is ſhifted farther to the northward or ſouthward, according as the ſun's declination is more northerly or ſoutherly.

In

In the Indian ocean there are *periodical winds*, called monſoons, that is, ſuch as blow ſix months in one direction, and the other ſix months in an oppoſite direction; the change of their direction, which is near the autumnal and vernal equinoxes, is accompanied with violent ſtorms of wind, thunder and lightning. Voyagers to India endeavour to time their voyages, ſo as to benefit by theſe winds.

On or near the coaſt of Guinea, the winds blow almoſt always from the weſt and ſouth weſt points. Between the Cape-Verd, and the eaſternmoſt of the Cape-Verd Iſlands, there is a tract of ſea, which is a perpetual calm with reſpect to wind; but the thunder and lightning there is terrible.

The varieties and deviations both in general and particular winds, are far from being known; you cannot, therefore, expect any theory that will ſolve them all; there are difficulties which perplex every hypotheſis that has hitherto been ſuggeſted, and that cannot be cleared up at preſent.

The beſt account we have of the trade-winds, is that of Mr. Dalton,* namely, That as the heat is always greateſt in the torrid zone, and decreaſes in proceeding northward and ſouthward, with reſpect to theſe, the poles may be always conſidered as centers of cold; ſo that, abſtracting from accidental circumſtances, there muſt be a conſtant aſcent of air over the torrid zone, which afterwards falls northward or ſouthward, whilſt the colder air below is determined by a conſtant impulſe towards the equator. In general, where the heat is greateſt, the heated air will aſcend, and a ſupply of colder air will be received from the neighbouring parts.

* Dalton's Meteorological Obſervations.

The following effects may be attributed to the diurnal motion of the earth; the air over any part thereof, when calm, will have the same rotatory velocity as that part; but if a quantity of air in the northern hemisphere receive an impulse in the direction of the meridian, either northward or southward, it's rotatory velocity will be greater in the former, and less in the latter case, than that of the air into which it moves; consequently, if it move northward, it will have a greater velocity eastward than the air, or surface of the earth over which it moves, and will, therefore, become a S. W. wind, or a wind between the south and the west. And, *vice versa*, if it move southward, it becomes a N. E. wind. Likewise, in the southern hemisphere, it will appear, the winds, upon similar suppositions, will be N. W. and S. E. respectively.

From this view of the air, Mr. Dalton attempts to explain the trade-winds; he considers two general masses of air, as proceeding from both hemispheres towards the equator; these, as they advance, are constantly deflected more and more towards the east, on account of the earth's rotatory motion. That from the northern hemisphere, originally a north wind, is made to veer more and more towards the east; and that from the southern hemisphere is made to veer from the south towards the east: these two masses meeting in the torrid zone, their north and south velocities destroy each other, and they proceed with their common velocity from east to west, round the torrid zone. The equator is not the center* of the concourse, but the northern parallel of 4°, because the center of heat is at that place, the sun being longer on the north side of the equator than on

* Prevost sur les Limites des Vents Alizez.

on the ſouth ſide. Though all the parts of the atmoſphere ſeem to conſpire in producing regular winds round the torrid zone, yet, from the ſituation of the land or other cauſes, ſtriking irregularities are produced ; as is evident by the monſoons, ſea and land breezes, &c. theſe are deviations from the general rule, but this will ever be more or leſs the caſe with all human theories.

To explain the *monſoons*, it is neceſſay to attend to the circumſtances that are peculiar to the *Indian ocean*, and which are not found in the Atlantic and Pacific oceans. They ſeem to be theſe: that the Indian ocean is bounded to the northward by ſhores, whoſe latitude does not *exceed* the limits of the general trade-wind ; and that the general trade-wind falls on what ſailors term lee ſhores to the weſtward.

The ſun being twice a year vertical in the equator, and never departing thence more than $23\frac{1}{2}$ degrees, cauſes the air in that climate to be hotter than at any other place in the ocean : ſuch a rarified ſpace muſt extend acroſs the Indian ocean, and produce a S. E. wind to the ſouthward, and a N. E. wind to the northward of the equator, over which, in the upper regions of the air, the winds return in the contrary direction. This we accordingly ſee happen in the months of October, November, December, January, February, March. But when the ſun declines to the northward, and heats the land there, the air contiguous to thoſe lands is rarified, and the lower air has a tendency to move that way : this tendency increaſes as the ſun advances further north, ſo that the whole body of the lower air, to the northward of the equator, moves towards the northern lands, notwithſtanding the equatorial rarifaction. It ſeems then, that the body of the lower air, in the northern part of the Indian ocean, is determined, as to it's courſe, by

by the greater rarifaction. If the rarifaction, at the ſurface of the land, be greater than that at the equator, the wind blows to the north; and the contrary happens, when the equatorial rarifaction is the greateſt.* Thus it appears, that it is the ſituation of the lands, and their effect in heating and rarifying the atmoſphere, which are the principal cauſes of the monſoons. Still, however, it muſt be owned, that the explanation is imperfect, and the obſervations we poſſeſs too few for forming a theory. In the commencement of the monſoons, to uſe the ſeamen's phraſe, they creep along ſhore, they then ſpread into the ocean: at firſt they are feeble, they afterwards become vigorous; they then gradually diminiſh, and finally come to a change; and this twice in a year, agreeable to our ſolar progreſs.

The ſun is the undoubted cauſe of the *ſea and land breezes*, which are wiſely appointed by *Divine Providence*, to make ſome of the hotter climates habitable. The *ſea breezes* in the Weſt-Indies begin to appear about nine o'clock in the morning, in a fine black curl upon the water, approaching the ſhore: it increaſes gradually till noon, and dies away at four or five in the afternoon. About ſix in the evening it changes to a *land breeze*, which blows from the land to the ſea, and laſts till eight in the morning. There is an interval in the morning and evening between the changing of the breezes, when the wind is ſtationary, like the water before the turning of the tide; and theſe intervals are the hotteſt parts of the day.

The breezes are thus accounted for: When the ſun is up, his heat takes more effect on the land than on the water, ſo that the heat is accumulated,

* Nicholſon's Philoſophy, Vol. 2. p. 61, and 62.

lated, and the air over the land is rarified; and as it mounts upward, the colder air from the ſea, comes in to keep up the equilibrium. In the evening the dews are ſo exceſſive, and the cold ſo ſudden on the land, from the quick deſcent of the ſun below the horizon, that the water in the night is warmer than the land; and the air of the ſea, being then moſt rarified, the draught of air is contrary to what it was in the day.

In the *northern* temperate zone, the winds are variable, but the moſt general are the S. W. and W. and the N. E. and E. In the northern temperate and frigid zones, the winds are more tempeſtuous in winter than ſummer.*

" In our climates, a tempeſt is but rarely known, and it's ravages are regiſtered as an uncommon calamity; but, in the countries that lie between the tropics, and for a good ſpace beyond them, it's viſits are frequent, and it's effects anticipated. In theſe regions the winds vary their terrors, ſometimes involving all things in a ſuffocating heat; ſometimes mixing all the elements of fire, air, water, earth together; ſometimes with a momentary ſwiftneſs paſſing over the face of the country, and deſtroying all things in their paſſage; and ſometimes raiſing whole ſandy deſerts in one country, to depoſit them in another. We have, therefore, very little reaſon to envy thoſe climates, the luxuriance of their ſoil, or the brightneſs of their ſkies. Our own cloudy atmoſphere, that wraps us round in obſcurity, though it fails to gild our proſpects with ſunſhine, or our groves with fruitage, nevertheleſs anſwers the calls of induſtry; the labourer toils in the certain expectation of a moderate but happy return."

The

* Dalton's Meteorological Obſervations, p. 88.

The rains in the Weſt-Indies are by no means the things they are with us. Our heavieſt rains are but dews comparatively: they are rather floods of water, poured from the clouds with a prodigious impetuoſity; the rivers riſe in a moment; new rivers and lakes are formed; and in a ſhort time all the low countries are under water.

It is in the rainy ſeaſon, principally in the month of Auguſt, that they are aſſaulted by hurricanes, which deſtroy at a ſtroke the labours of many years, and proſtrate the moſt exalted hopes of the planter, and that, often when he thinks himſelf out of the reach of fortune. It is a ſudden and violent ſtorm of wind, rain, thunder and lightning, attended with a furious ſwelling of the ſeas, and ſometimes with an earthquake; in ſhort, with every circumſtance which the elements can aſſemble, that is terrible and deſtructive. Firſt, they ſee, as a prelude to the enſuing havock, whole fields of ſugar canes whirled into the air, and ſcattered over the face of the country. The ſtrongeſt trees of the foreſt are torn up by the roots, and driven about like ſtubble; their wind-mills are ſwept away in a moment; their works, the fixtures, the ponderous copper-boilers, and ſtills of ſeveral hundred weight, are wrenched from the ground and battered to pieces; their houſes are no protection; their roofs are torn off at one blaſt, whilſt the rain, which in an hour riſes five feet, ruſhes in upon them with irreſiſtible violence.

There are ſigns by which the Indians of theſe iſlands taught our planters to prognoſticate the approach of an hurricane. The hurricane comes on either in the quarter or at the full change of the moon. If it comes on at the full, then, at the preceding change, the ſky is troubled, the ſun more red than uſual; there is a dead calm below, and the mountain tops are free from thoſe miſts which

uſually

ufually hover about them. In the caverns of the earth, and in wells, you hear a hollow rumbling found, like the rufhing of a great wind. At night the ftars feem much larger than ufual, and furrounded with a fort of burs; the north-weft fky has a black and menacing appearance; the fea emits a ftrong fmell, and rifes into vaft waves often without any wind. The wind itfelf now forfakes it's ufual fteady eafterly ftream, and fhifts about to the weft; from whence it fometimes, with intermiffions, blows violently and irregularly about two hours at a time. You have the fame figns at the full moon: the moon herfelf is furrounded with a great bur, and fometimes the fun has the fame appearance.

The nature of the foil over which the wind blows has a great effect upon the quality of the air: the vaft fandy deferts of Africa and Arabia give a burning heat, and blafting quality, to the air that paffes over them. Thefe horrid regions lie to the fouthward and eaftward of the Mediterranean; and hence it is that travellers, who have had the opportunity of making the comparifon, tell us, that the air of the Weft India iflands is nothing to the hot fuffocating winds which blow in the night at Minorca and Gibraltar, for thefe latter are fcarcely fupportable by the human frame. At Goree, in the river Senegal, there is an eafterly wind from the inland parts, with which thofe who are fuddenly met by it in the face are fcorched up as by a blaft from a furnace.

An extraordinary blafting wind is felt occafionally at Falklands Iflands. Happily it's duration is fhort: it feldom continues above twenty-four hours. It cuts the herbage down as if fires had been made under them; the leaves are parched up, and crumble into duft. Fowls are feized with cramps, fo as never to recover. Men are oppreffed with

with a ſtopped perſpiration, heavineſs at the breaſt, and ſore throat; but recover with care.

But beyond all others in it's dreadful effects, is the *ſamiel*, or mortifying wind, of the deſarts near Bagdad. The camels, either by inſtinct or experience, have notice of it's approach; and are ſo well aware of it, that they are ſaid to make an unuſual noiſe, and cover up their noſes in the ſand. To eſcape it's effects, travellers throw themſelves as cloſe as poſſible to the ground, and wait till it has paſſed by, which is commonly in a few minutes. As ſoon as they who have life dare to riſe again, they examine how it fares with their companions, by plucking at their arms or legs; for if they are deſtroyed by the wind, their limbs are abſolutely mortified, and will come aſunder. It is ſaid of this wind, that if it happens to meet with a ſhower of rain in it's courſe, and blows acroſs it, it is at once deprived of it's noxious quality, and becomes mild and innocent. It is alſo ſaid, that it was never known to paſs the walls of a city.

OF THE AURORA BOREALIS.

No perſon has paid ſo much attention to this ſubject as Mr. Dalton; he is alſo the only one that I know of who has given a clear and ſatisfactory account of this phenomenon. To his work I muſt refer you; contenting myſelf here with laying before you his account of the appearances of the *aurora borealis*, without entering into his explanation thereof.

The appearances of the aurora come under four different deſcriptions. 1ſt, A *horizontal* light, like the morning aurora, or break of day. 2dly, Fine, ſlender, luminous *beams*, well defined, and of denſe light. Theſe often continue a quarter, an half, or a whole minute apparently at reſt, but oftener

oftener with a quick lateral motion. 3dly, *Flashes* pointing upward, or in the same direction as the beams, which they always succeed. These are only momentary, and have no lateral motion; but they are generally repeated many times in a minute. They appear much broader, more diffuse, and of a weaker light than the beams: they grow gradually fainter till they disappear; and sometimes continue for hours, flashing at intervals. 4thly, *Arches*, nearly in the form of a rainbow: these when complete, go quite across the heavens, from one point of the horizon to the opposite point.

When an *aurora* happens, these appearances seem to succeed each other in the following order: 1. the faint *rainbow-like arches*; 2. the *beams*; and 3. the *flashes*. As for the northern horizontal light, it appears to consist of an abundance of *flashes*, or *beams*, blended together by the situation of the observer.

The *beams* of the aurora borealis appear at all places to be arches of great circles of the sphere, with the eye in the center; and these arches, if prolonged upwards, would all meet in one point.

The *rainbow-like arches* all cross the *magnetic meridian* at right-angles. When two or more appear at once, they are concentric, and tend to the east and west; also the broad arch of the *horizontal light* tends to the magnetic east and west, and is bisected by the magnetic meridian; and when the *aurora* extends over any part of the hemisphere, whether great or small, the line separating the illuminated part of the hemisphere from the clear part, is half the circumference of a great circle crossing the magnetic meridian at right-angles, and terminating in the east and west: moreover, the beams perpendicular to the horizon are only those on the magnetic meridian.

That

That point in the heavens to which the *beams* of the *aurora* appear to converge, at any place, is the ſame as that to which the ſouth pole of the dipping needle points at that place.

The *beams* appear to riſe above each other in ſucceſſion; ſo that of any two beams, that which has the higher baſe has alſo the higher ſummit.

Every *beam* appears broadeſt at or near the baſe, and to grow narrower as it aſcends; ſo that the continuation of the bounding lines would meet in the common center to which the beam tends.

The height of the *rainbow-like arches* of the *aurora*, are eſtimated by Mr. Dalton to be above the earth's ſurface about 150 Engliſh miles.

OF THE SOURCES OF HEAT AND COLD.*

If the changes of the weather depended on the courſe of the year, and the temperature of climates were governed by their ſituation with reſpect to the ſun, that is, by their latitude, then the weather might be reduced to ſome regular theory. But this is ſo far from being the caſe, that the latitude of a place cannot be conſidered as an index to the temperature of the climate: for we find the hotteſt days in the coldeſt climates; and the coldeſt weather, and even perpetual ſnow, are found in countries bordering on and immediately under the equator; ſo that we muſt recur to ſome other cauſes beſides the immediate influence of the ſolar rays.

1. But though the ſun is not the only cauſe, it's preſence is undoubtedly the principal ſource of heat as well as light, and it's abſence the primary cauſe of cold. It is indeed the great ſpirit of the world:

* Kirwan's Eſtimate of the Temperature of different Latitudes.
Jones's Phyſiological Diſquiſitions.

world: all things revive at his approach; winter and froſt lay behind him.

2. The ſecond ſource of heat is the earth. Nobody has yet been found ſo abſurd as to ſuppoſe that human perſpiration was owing to the air that ſurrounds the ſkin; it originates in an internal cauſe; it is occaſioned by a heat within, not the air without. It is the ſame with reſpect to the earth; which, by imparting it's heat to the atmoſphere, moderates the rigour of the winter's cold. Whether we ſuppoſe that this heat ariſes from a central ſource, or that the globe, from it's firſt creation, was endued with a heat ſufficient for all the purpoſes it was intended to anſwer; yet it is evident that it is renewed and preſerved by the influence of the ſun, and that there is always a ſilent and imperceptible heat proceeding from the earth.

Mr. *de Luc* ſhews, that our globe has a proviſion of fire ſpread through it's whole maſs; ſo that wherever there is no chemical operation to diſengage or to abſorb it, this fire maintains the ſame degree of expanſive force. From obſervation we alſo find, that the ſame degree of heat reigns in all ſubterraneous places, except in mines where there is reaſon to ſuſpect ſome chemical operation. With reſpect to thoſe parts of the globe which are neareſt the ſurface, the fire paſſes therefrom into the air, when it's expanſive force exceeds that of the fire in the air, and *vice verſa*. Thus a certain equilibrium is preſerved near the ſurface, though ſubject to certain viciſſitudes.

The ſolar rays exerciſe two diſtinct functions; in the one acting as fire, in the other increaſing the expanſive force of the exiſting fire. Various combinations of fire are continually forming, as well upon the ſurface of the globe as in the atmoſphere; combinations which are afterwards under other circumſtances deſtroyed. Theſe compoſitions and de-

compofitions occafion the greater part of terreftrial phenomena.

3. The next great fource of heat is the condenfation of vapour. Vapour contains a quantity of fire: it is this fire which caufes it to affume, and fupports it in an aerial expanded ftate: when condenfed into a liquid form, it lets go this fire, which warms the furrounding atmofphere; hence the fultrinefs frequently experienced before rain.

OF THE SOURCES OF COLD.

1. As the earth is one of the principal fources of heat in the atmofphere that furrounds it, fo is diftance from the earth a fource of cold; the greateft cold prevailing in the higheft regions of the atmofphere: for where the re-action is wanting by a fuperficial preffure, but little effect can be received from the rays of the fun; and it is further proved, by experiments with the burning-glafs, that a clear unclouded air receives no heat from thefe rays. Hence, when we afcend to a lighter air, at a diftance from the furface, the heat is not fufficient to melt the fnow; and we find the higheft mountains, even under the equinoctial, perpetually covered therewith: thus the mean height of the lower term of congelation, in winter, in this latitude, may be confidered in general to be at 6260 feet from the furface, and the mean height of the upper term at 1125 feet. We cannot in this Lecture confider any of the minute exceptions.

Sir William Young gives a remarkable inftance of the effect of hills, in arrefting vapours, and producing rain, while the exhalations from the trees on it's furface cool and temper the air; obferving, that the fmooth polifhed Barbadoes, and our Leeward Iflands, are parched up, whilft the towering and rugged Dominica, St. Vincent, Grenada,

Grenada, and Tobago, enjoy inceſſant rains, and delicious verdure.

It is generally agreed, that the clearing away of wood in time leſſens the vapours, and conſequently the rain of a country. Several fine pariſhes in Jamaica, which uſed to produce large crops of ſugar canes, and were once the richeſt ſpots in the iſland, are now dry for nine months in the year, and are turned into cattle-pens, through the clearing away of the neighbouring woods.

Water is very plentiful in thoſe countries where woods and foreſts abound, and the pureſt ſprings are generally found beneath the friendly ſhelter of a grove.

The natural hiſtory of every country ſhews, that in proportion as the woodlands are cleared, the water courſes diminiſh.

In America, unfortunately for the inhabitants, this truth is too well known; for ſince the woods in the vicinity of their towns have been cut down, many long eſtabliſhed mill races have become dry, and others have been reduced ſo low, as to cauſe very great interruptions to the miller, who muſt wait a conſiderable time for the dams to fill between every few hours work.

Hence we may learn the important neceſſity of preſerving the trees, from beneath whoſe humid ſhades a water ſpring diſcharges it's ſtreams; and hence, too, we may learn, that the ſmalleſt ſprings may be improved by planting around them a grove of trees, particularly the oak, ſo highly valued by the Greeks, the Romans, and our ancient Druids; who, conſidering the health of man, and the fertility of the ſoil, to be abſolutely dependent upon plenteous ſtreams of water, *conſecrated their groves* to preſerve their ſprings.

2. The next great ſource of cold is evaporation. The ſame cauſe which makes the con-

denſation of vapour a ſource of heat, makes evaporation productive of cold; as it abſorbs the fire in the latter inſtance, which it gives out in the former: it is this which gives the particles of vapour their aerial form. When fire paſſes from fluids which it has heated, it's courſe is upwards, and it always carries with it a thin ſtratum of the fluid in the form of vapour: thus evaporation not only tempers the heat occaſioned by the ſun's rays, but is one great ſource of cold.

OF EVAPORATION.

Of evaporation it may be obſerved, 1. That in our climates the quantity of it is four times greater from the 21ſt of March to the 21ſt of September, than it is from the 21ſt of September to the 21ſt of March.

2. That it is greater in proportion as the difference in temperature between the air and evaporating ſurface is greater; though if the air be 15 degrees colder than the evaporating ſurface, there is no evaporation, but a depoſit of moiſture from the air.

3. The degree of cold produced by evaporation, is always much greater when the air is warmer than the evaporating ſurface, than that which is produced when this ſurface is warmer than the air. Hence warm winds, as the Serocco and Harmatan, are more deſiccative than cold winds.

4. Evaporation is more copious when the air is leſs loaded with vapours, and is conſequently powerfully promoted by cold winds flowing into warmer countries.

5. That it is greatly increaſed by a current of air, or wind, flowing over the evaporating ſurface; not only becauſe the evaporating ſurface is thereby increaſed, but alſo becauſe the vapour is thereby removed,

removed, and prevented from attaining it's maximum: hence it is generally remarked, that calm days are the hottest.

6. Tracts of land covered with trees or vegetables, emit more vapour than the same space covered with water: on this principle it is, that the air about a wood or forest is made colder by the evaporation from trees and shrubs, while the plants themselves are kept in a more moderate heat, and secured from the burning heat of the sun, by the vapour perspired from the leaves. Thus we find the shade of vegetables more effectual to cool us, as well as more agreeable, than that from rocks and buildings.

7. The heat and cold of different countries are transmitted from one country to the other, by the medium of winds.

Of Annual Temperature.

Within ten degrees of the pole there is very little difference in the annual temperature, nor is there much within ten degrees of the equator.

The temperature of different years differs very little near the equator, but they differ more and more as their latitudes approach the pole.

It scarce ever freezes, unless in very elevated situations, in latitudes under 35°; and it scarce ever hails in latitudes higher than 60°.

Between the latitudes of 35° and 60°, in places adjacent to the sea, it generally thaws when the sun's altitude is 40°, and seldom begins to freeze until the sun's meridian altitude is below 40°.

The greatest cold in all latitudes in our hemisphere, is generally about half an hour before sunrise: the greatest heat in all latitudes between 60° and 45°, is found to be about half past two o'clock in the afternoon; between latitudes 45° and 35°, at

two o'clock; between latitudes 35° and 25°, at half paſt one; and between latitude 25° and the equator, at one o'clock.

The month of January is the coldeſt in every latitude. July is the warmeſt month in all latitudes above 48°; but in lower latitudes Auguſt is generally the warmeſt.

December and January differ but little, and there is no great difference between June and July. In latitudes above 30°, the months of Auguſt, September, October, and November, differ more from each other than thoſe of February, March, April, and May; in latitudes under 30° the difference is not ſo great. The temperature of April approaches more every where to the mean annual temperature than that of any other month: whence we may infer, that the effects of natural cauſes, operating over a large extent, do not arrive at their maximum until the cauſes begin to diminiſh; but that after theſe effects have arrived at their maximum, the decrements are more rapid than the increments originally were, during their progreſs to that maximum.

The differences between the hotteſt and the coldeſt months, within twenty degrees of the equator, are inconſiderable, except in ſome peculiar ſituations; but they increaſe in proportion as we recede from the equator.

In the higheſt latitudes, we often meet with a heat of 75° or 80°; and particularly in latitudes 59° and 60°, the heat of July is frequently greater than in latitude 51°.

At the time of the equinoxes, when the ſun paſſes from one hemiſphere into the other, there is generally ſome diſturbance in the weather; the winds are then moſtly higher: at the vernal equinox, they are for the greater part eaſterly, cold, dry, and ſearching. The ſolſtitial point of the ſummer

summer is more apt to be distinguished by violent rains, and what we call a midsummer flood. The winter being less rainy than the summer, nothing particular happens at the winter solstice, except that the frost sets in more severely, with some continuance of snow, which lies long upon the ground.

The temperature of a climate depends on many circumstances, particularly on the disposition of the land; as it's elevation, it's exposure to the winds, and the course of the mountains that are found in it. Thus the writer of Anson's voyage informs us, that while they coasted near the land of South America, which has those vast ridges of mountains, the Andes and Cordillieras, the air was rendered temperate by the wind that blew over them; but when they had passed beyond this tract of land, and sailed by the isthmus of Darien, where the country is flatter, the air became insupportably close and sultry.

All countries lying to the *windward of high mountains*, or extensive forests, are warmer than those to the leeward in the same latitude.

The *vicinity to the sea* is another circumstance which affects the temperature of a climate; as it moderates the heats from the land, and brings the atmosphere down to a standard best fitted to the human constitution. This is probably the reason why there is so great a proportion of sea on the terraqueous globe, and particularly why it is so largely distributed about the middle region of the earth. In our hemisphere, countries that lie southward of any sea, are warmer than those that have that sea to the south of them; because the winds that should cool them, in winter are mitigated by passing over the sea; whereas those that are northward of the sea, are cooled in summer by the breezes from it. A northern or southern bearing

of the ſea renders a country warmer than an eaſtern or weſtern bearing.

Iſlands participate more of temperature ariſing from the ſea, and are therefore warmer than continents. Moſt large iſlands have their greateſt extent from north to ſouth. With us, the ſouthern parts are proportionably colder than the northern. A ridge of mountains generally traverſes iſlands in the direction of their length.

The ſoil of large tracts of land has it's ſhare in influencing the temperature of the weather: thus ſtones or ſand heat and cool more readily, and to a greater degree, than the earth or vegetable mould; hence the violent heats of the moſt ſandy deſarts of Arabia and Africa, and the burning heat and blaſting qualities of the wind that paſſes over them; hence alſo the intenſe cold of Terra del Fuego, and other ſtony countries, in cold latitudes.

Living vegetables have a conſiderable effect in altering climates, and affecting the weather. Wooded countries are much colder than thoſe that are open and cultivated: thus part of Guiana has only been cleared from wood ſince the beginning of this century, and the heat in that part is already exceſſive; whereas in the wooded parts the inhabitants are obliged to light a fire every night.

Every habitable latitude enjoys a heat of 60 degrees at leaſt, for two months; which heat ſeems neceſſary, for the growth and maturity of corn. The quickneſs of vegetation in the higher latitudes, proceeds from the duration of the ſun over the horizon. Rain is little wanted, as the earth is ſufficiently moiſtened by the liquifaction of the ſnow, that covers it during the winter. In all this, we cannot ſufficiently admire the wiſe diſpoſition of Providence.

It is owing to the ſame provident hand, that the

the globe of the earth is interſected with ſeas and mountains, in a manner, that on it's firſt appearance ſeems altogether irregular and fortuitous; preſenting to the eye of ignorance, the view of an immenſe ruin: but when the effects of theſe ſeeming irregularities, on the face of the globe, are carefully inſpected, they are found moſt beneficial, and even neceſſary to the welfare of it's inhabitants; for, to ſay nothing of the advantages of trade and commerce, which could not exiſt without theſe ſeas; we have ſeen, that it is by their vicinity, that the cold of the higher latitudes is moderated, and the heat of the lower. It is by the want of ſeas, that the interior parts of Aſia, as Siberia and Great Tartary, as well as thoſe of Africa, are rendered almoſt uninhabitable; a circumſtance which furniſhes a ſtrong prejudice againſt the opinion of thoſe, who think theſe countries were the original habitations of man. In the ſame manner, mountains are neceſſary, not only as the reſervoirs of rivers, but as a defence againſt the violence of heat in the warm latitudes. Without the Alps, Pyrenees, Apennine, the mountains of Dauphine, and Auvergne, &c. Italy, Spain, and France, would be deprived of the mild temperature they at preſent enjoy: without the Balgate hills, or Indian Apennine, India would have been a deſart: hence Jamaica, St. Domingo, Sumatra, and moſt other intertropical iſlands, are furniſhed with mountains, from which the breezes proceed that refreſh them.

Of Atmospherical Electricity.

So little is known with any certainty, concerning *atmoſpherical electricity*, that I ſhall detain you but a ſhort time with what I have to ſay thereon. If every ſolution of continuity, every expanſion

expanſion and contraction of material ſubſtances, are ſources of electrical appearances, we need not be ſurprized at finding it in great abundance among the clouds: in this view of the ſubject, the perpetual oſcillations of the air muſt be alſo a means of rendering it ſenſible to us. Mr. Bennet's * electrometer, which I have already deſcribed, is the beſt and readieſt inſtrument for obſerving the changes in the electricity of the atmoſphere.

The following poſitions have been deduced from ſome obſervations on the electrical ſtate of the atmoſphere. 1ſt. That in the ſpring, when plants begin to grow, we are told, that temporary electrical clouds begin to appear, and pour forth electric rain. 2d. That the electricity of the clouds and of the rain increaſes, till that part of autumn, when the laſt fruits are gathered. It is hence ſuppoſed to actuate and animate vegetation, and to give to rain that power, which renders it more propitious to vegetables than any other kind of watering.

Aerial electricity varies according to the ſituation; it is generally ſtrongeſt in elevated and inſulated ſituations; not to be obſerved under trees, in ſtreets, in houſes, or any incloſed places; though it is ſometimes to be found pretty ſtrong on quays and bridges. It is alſo not ſo much the abſolute height of the places, as their ſituation; thus a projecting angle of a high hill will often exhibit a ſtronger electricity than the plain at the top of the hill, as there are fewer points in the former to deprive the air of it's electricity.

The intenſity of the atmoſpheric electricity is varied by a great many circumſtances, ſome of which may be accounted for, others cannot. When the

* See the Rev. Mr. Bennet's New Experiments on Electricity. Derby, 1789.

the weather is not ferene, it is impoffible to affign any rule for their variation, as no regular correfpondence can then be perceived with the different hours of the day, nor with the various modifications of the air. The reafon is evident; when contrary and variable winds reign at different heights, when clouds are rolling over clouds, thefe winds and clouds, which we cannot perceive by any exterior fign, influence, however, the ftrata of air in which we make our experiments, produce thofe changes of which we only fee the refult, without being able to affign either the caufe, or it's relation. Thus, in ftormy weather, we fee the electricity ftrong, then null, and in a moment after arife to it's former force; one inftant vitreous, the next refinous; without being able to affign any reafon for thefe changes. Mr. de Sauffure fays, that he has feen thefe changes fucceed with fuch rapidity, that he had not time to note them down.

When rain falls without a ftorm, thefe changes are not fo fudden; they are, however, very irregular, particularly with refpect to the intenfity of force; the quality thereof is more conftant. Rain or fnow almoft uniformly give vitreous electricity.

The ftate of the air, in which the electricity is ftrongeft, is foggy weather; this is always accompanied with electricity, except when the fog is going to refolve into rain.

The moft interefting obfervations, and thofe which throw the greateft light upon the various modifications of electricity in our atmofphere, are thofe that are made in ferene weather. In winter, (during which moft of Mr. de Sauffure's obfervations were made) and in ferene weather, the electricity was generally weakeft in an evening, when the dew had fallen, until the moment of the fun's rifing; it's intenfity afterwards augmented by degrees,

grees, ſometimes ſooner, and ſometimes later; but generally before noon it attained a certain maximum, from whence it again declined, till the fall of the dew, when it would be ſometimes ſtronger than it had been during the whole day; after which, it would again gradually diminiſh during the whole night; but is never quite deſtroyed, if the weather is perfectly ſerene.

Atmoſpherical electricity ſeems, therefore, like the ſea, to be ſubject to *a flux and reflux*, which cauſes it to increaſe and diminiſh twice in 24 hours. The moments of it's *greateſt* force are ſome hours *after the riſing and ſetting of the ſun*; thoſe when it *is weakeſt, precede the riſing and ſetting thereof.*

The electricity of ſerene weather is much weaker in ſummer than in winter, which renders it more difficult to obſerve theſe gradations in ſummer than in winter; beſides a variety of accidental cauſes, which at the ſame time render them more uncertain. In general, in ſummer, if the ground has been dry for ſome days, and the air is dry alſo, the electricity generally increaſes, from the riſing of the ſun till 3 or 4 in the afternoon, when it is ſtrongeſt; it then diminiſhes till the dew begins to fall, which again reanimates it; though after this it declines, and is almoſt extinguiſhed during the night.

But the ſerene days that ſucceed rainy weather in ſummer, generally exhibit the ſame diurnal periods or ſtates of electricity, as are to be obſerved in winter.

ON PROGNOSTIC SIGNS OF THE WEATHER.

There is no part of meteorology which intereſts mankind ſo much, as the predictions it furniſhes of the change of weather. The theory of it only engages

engages the attention, by animating us with the hopes of thereby bringing the knowledge of these predictions to perfection.

And the far greater part of those who purchase meteorological instruments, buy them, not so much to know the actual state of the elements, as to foresee the changes thereof. This science is, however, very imperfect; for it is but of late years that we began to make observations on the changes of the weather; and that it's progress has been rapid and successful, may be seen in the works of De Luc, De Saussure, Jones, Marshall, and Kirwan. But these observations will be still more valuable to posterity; for we can scarce expect them in sufficient number in our own age, to deduce from them a general and perfect theory.

To attain this end, it will be necessary to multiply observations on as great a number of signs as possible; for it is only by their combination and concurrence that we can expect to remove the uncertainty inseparable from each in itself. Thus the barometer is not always a certain sign; the same may be said of the thermometer, the hygrometer, and the action of winds. But if they all concur together, there is but little chance of being deceived; and there would be still less, if to these were joined other signs, which are easy to observe, and which by their combination would render our prediction certain.

No sign, nor any instrument of observation, should therefore be neglected, either from a love of ideal perfection, or fears of inaccuracy. Thus, though the hygrometer be at present a very imperfect instrument, yet one certain sign has already been obtained from it's indications, and more may be reasonably expected. Even the words *very dry, very moist, moderately dry, moderately moist,* though

though of vague determination, may throw much light on the ſtate of the atmoſphere.

It is neceſſary that the obſerver ſhould enter into a preciſe detail of the various ſtates of the ſky, and the clouds. What can we learn from the words *covered*, and *cloudy*, or *half covered ſky*, &c.? Nothing, ſince it is well known, that a covered ſky, in one caſe, is almoſt as certain an indication of fine weather, as in another, it is an indubitable preſage of rain. The accurate obſerver piques himſelf on a thermometer, with which he can obſerve within a degree, and a barometer that he can depend upon to leſs than the 100dth of an inch; but is ſilent on the tranſparency of the air, on dews, on the elevation, the form, the ſign, the diſpoſition, the colour, and the denſity of the clouds; things that may be obſerved with eaſe, and deſcribed without trouble; being attended with no other inconvenience than that of extending the ſize of our meteorological tables.

There is a phenomenon, which has not been ſufficiently attended to, namely, the *undulating motion* of the firmament, or that *diurnal tumult in the air*, which is kept up by the heat of the ſun. What the ſun raiſes from the earth by the heat of the day, is ſuſtained in the atmoſphere by it's heat, and the agitation, or expanſive undulation of the air. This motion is often viſible to the naked eye, but in the field of a powerful teleſcope it is very conſpicuous; all objects appear in violent agitation, and the line of the ſenſible horizon, which ought to be clear and well defined, is waved like a field of corn in the wind, or the ſurface of the ſea in a ſtorm. So long as this agitation continues, the vapours ſtay in the air; but when it ſubſides, and the ſun departs, they are condenſed, and fall down to the earth in the night as dew.

In

In the present ſtate of this part of ſcience, when we are unacquainted with ſo many phenomena, and ſtill more ignorant of their cauſes, general rules will often be found to fail, and particular ones will, without much circumſpection, prove to be a ſource of error. Amongſt the variety of means for predicting the changes of the weather, the barometer is undoubtedly one of the beſt; and is in this, as well as many other reſpects, one of the greateſt acquiſitions to natural philoſophy.

The uſual ranges of the mercurial column, in this latitude, are comprized between 28 and 31 inches; of which the middle, or $29\frac{1}{2}$, is conſidered as the variable: I think it ſhould be placed ſomewhat higher. Near the pole, the variations of the barometer are much greater.

OF PROGNOSTICS BY THE BAROMETER.

Ever ſince the barometer has been invented, philoſophers have endeavoured to account for the variations in the height of a local barometer, but hitherto in vain. Mr. de Luc, in the firſt volume of his "Recherches ſur les Modifications de l'Atmoſphere," has given a critical and very intereſting account of the various phyſical opinions that have been invented for this purpoſe by Paſcal, Beale, Wallis, Garden, Halley, &c. &c. and ſhewn that they are all imperfect, and inadequate to the ſolution of the phenomena. He then propoſes one of his own; which, with that candour that ever diſtinguiſhes a lover of truth, he has ſince abandoned. To give a particular account of the various hypotheſes, would occupy a volume, and that to little purpoſe. As I know of none that can be depended on, I ſhall content myſelf with only relating the bare phenomena. The two great ſources of error on this ſubject have been, 1ſt, the difficulty

culty of obſerving the whole of the appearances; and 2dly, the facility with which the mind embraces and ſupports a favourite hypotheſis.

There is one ſtriking phenomenon in the variations of the barometer, which ſhould be particularly attended to in every theory, becauſe it is as great as it is certain and invariable; namely, that the variations diminiſh in proportion as you approach the equator, and augment as you advance towards the poles. The countries, however, that are ſituated about the equator, are ſubject to changes of the weather, though it is more conſtant there than in the temperate climates: there are changes there of humidity and dryneſs, rains and fair weather, ſtorms and tempeſts, &c. much more violent than with us; and yet all theſe take place without any way affecting the barometer.

MR. DALTON'S GENERAL RULES AND OBSERVATIONS FOR JUDGING OF THE WEATHER.

1. The barometer is higheſt of all during a long froſt, and generally riſes with a N. E. wind; it is loweſt of all during a thaw following a long froſt, and is often brought down by a S. W. wind.

2. When neareſt the high extreme for the ſeaſon of the year, there is very little probability of immediate rain.

3. When barometer is low for the ſeaſon, there is ſeldom a great weight of rain, though a fair day in ſuch a caſe is rare. The general tenor of the weather at ſuch times is, ſhort, heavy, and ſudden ſhowers, with ſqualls of wind from the S. W. W. or N. W.

4. In ſummer, after a long continuance of fair weather, with the barometer high, it often falls gradually, and for one, two, or more days before, there is much appearance of rain. If the fall be ſudden

ſudden and great for the ſeaſon, it will probably be followed by thunder.

5. When the appearances of the ſky are very promiſing for fair weather, and the barometer at the ſame time low, it may be depended upon that the appearances will not remain ſuch long. On theſe occaſions the face of the ſky changes very ſuddenly.

6. Very dark and denſe clouds paſs over, when the barometer is high, without rain; but when the barometer is low, it ſometimes rains almoſt without any appearance of clouds.

7. All appearances being the ſame, the higher the barometer is, the greater is the probability of fair weather.

8. Thunder is generally preceded by hot weather, and followed by cold and ſhowery weather.

9. A ſudden and extreme change of temperature of the atmoſphere, either from heat to cold, or cold to heat, is generally followed by rain within 24 hours.

10. In winter, or during a froſt, if it begins to ſnow, the temperature of the air generally riſes to 32°, and continues there while the ſnow falls; after which, if the weather clears up, expect ſevere cold.

11. The aurora borealis is a prognoſtic of fair weather.

Further Indications of the Weather by the Barometer.

In general, when the barometer falls, there is rain; but when the mercury riſes, it is a ſign of fair weather.

If the mercury falls in a froſt, we may expect ſnow, or a thaw; but if it riſes in winter, with a north or eaſt wind, it generally portends a froſt.

If the mercury ſinks ſlowly and gradually, we may expect that the rain will be of ſome conti-

nuance; and if the riſe be gradual, we may judge that the fine weather will be laſting. If it fluctuates much, riſing and falling ſuddenly, the weather is unſettled and changeable: if it falls very low, there will be much rain; but if it's falls are low and ſudden, a high wind generally enſues: when exceeding low, ſtorms and tempeſtuous weather may be expected; but if an extraordinary fall happens, without any remarkable change near at hand, it is probable that there is a ſtorm at a diſtance.

The deſcent of the barometer is not, however, always an indication of rain, for it will often fall for wind; nor is it's riſe a certain ſign of fair weather, particularly if the wind be northerly or eaſterly. If the fine weather be laſting, with a weſterly wind, the mercury generally reſts a little above changeable, but ſomewhat below thirty inches.

In the ſummer months the barometer does not vary ſo much as in winter; the greateſt variations are in the firſt two, and the laſt two months of the year, but particularly in the firſt and laſt. A north-eaſt wind generally makes the barometer in this country riſe, and it is generally loweſt with a ſouth-weſterly wind.

If the mercury continues to fall while it rains, it will be likely to rain the next day: when the mercury is pretty high, and has fallen to foretel rain, and yet riſes before the rain falls, it is an indication that there will be but little. In fair weather, when the mercury has continued high and riſing, if it falls about noon, and riſes again towards the evening, a ſingle ſhower may be expected on the evening or noon of the next day, and then fair weather. When the mercury riſes gradually about half a tenth, and continues to do ſo for many days, the fair weather may be expected to continue for ſome time, unleſs wind intervenes, particularly from the S. W. by S.

FROM

FROM THE THERMOMETER.

In winter, if the cold diminiſhes ſuddenly, it in general portends rain; in ſummer, a ſudden augmentation of heat is alſo a forerunner of rain.

FROM THE BAROMETER AND THERMOMETER.

If the air in foggy weather becomes hotter by the action of the ſun alone, the fog generally diſſipates, and the air remains ſerene: but if the barometer falls, and the change of temperature be from a ſouth or ſouth-weſt wind, the fog riſes and forms itſelf into clouds, and it's aſcenſion is generally a ſign of rain.

FROM THE BAROMETER, HYGROMETER, WIND, AND STATE OF THE SKY.

The barometer being high and ſtationary, the natural and factitious hygrometers indicating dry air, the canopy of the ſky lofty, and the wind north-eaſterly, are the ſureſt ſigns of *ſettled fair;* while a light and moiſt atmoſphere, the canopy of the ſky low, and a ſouth-weſt wind, certainly portend a wet ſeaſon.

FROM CLOUDS.

When the clouds are formed like fleeces deep and denſe towards the middle, and very white at the edges, with a bright blue ſky about them, they generally ſoon fall in hail, ſnow, or in haſty ſhowers of rain. In the north of England, ſuch clouds are called woolpacks.

There is no ſign of rain more certain than two different currents of clouds, eſpecially if the under-

moſt flies faſt before the wind; when this happens in ſummer, there is ſeldom wind at the time, and thunder generally follows. In winter the light vapour, or ſcud, as the ſailors call it, often comes rapidly againſt the wind, and a gale is ſoon after expected.

The *tranſparency of the air* is to the inhabitants of the Alps one of the moſt certain ſigns of rain; when the diſtant objects appear diſtinct and well defined, when the *ſky is of a deep blue*, they conſider rain as near at hand, though no other ſigns appear. I have been informed by a gentleman to whom I am under obligations for other obſervations, that this ſign, from the *tranſparency of the air*, is by no means local, but is often obſerved in England, that in ſuch a ſtate of the air, the ſailors ſay the land, or other object, looms near, and expect bad weather.

When the ſky, in a rainy ſeaſon, is tinged with a ſea-green colour, particularly near the horizon, when it ought to be blue, the rain will continue and increaſe. If it be of a deep dead blue, it will be ſhowery: this is more particularly found to hold true near the ſea coaſt.

Clouds of a ſimilar appearance produce thunder in ſummer, and ſnow in winter; ſuch clouds are broken, and irregularly ſhaped, heaped one on another, and from their uncommon denſity project towards the earth. After a thunder ſtorm, if it has been of conſiderable duration, the wind generally (if not always) veers to the quarter from whence the firſt clap proceeded.

A cloſe ſultry day, when the current of air is ſcarcely perceptible, is often ſucceeded by a change in the wind.

The wind ſhifting from point to point round the compaſs, generally denotes rain. If, after a continued rain from a muddy ſky, the horizon appears lighter

lighter in any quarter, expect the wind from that quarter.

I found the following table of the ſtate of the weather among my father's papers: it appears to me worthy of attention.

THE GENERAL STATE OF THE WEATHER WHEN THE MERCURY IN THE BAROMETER REMAINS STATIONARY ON ANY OF THE UNDERMENTIONED DEGREES, 12 OF WHICH ARE EQUAL TO AN ENGLISH INCH.

The outer numbers are the correſponding inches and parts.

Inch.	parts.		
31		16.	Settled, fine clear ſky.
	.92	15.	Summer, very warm; winter, hard froſt.
	.83	14.	Great drought.
	.75	13.	Pleaſant ſerene weather.
	.67	12.	Settled.
	.58	11.	Summer, cloſe and rainy; winter, ſnow, and foggy.
	.50	10.	Clear.
	.42	9.	Rain or wind; winter, ſnow or miſt.
	.33	8.	Fine weather.
	.25	7.	Rain or wind.
	.17	6.	Good but uncertain weather.
	.08	5.	Generally miſty when the thermometer is under 60 deg.: otherwiſe, thick, rain or wind; but in ſummer with an eaſterly-wind, clear.
30		4.	Good weather.
	.92	3.	Stormy with a north-weſterly wind; otherwiſe, raw, hazy, cloudy weather; in ſummer, thunder.
	.83	2.	Moderate weather.

Inch. parts.		
.75	1.	Rain, thunder, wind; in winter, with a northerly wind, raw, cold, ſnow, or miſt.
.67	0.	Variable.
.58	1.	Moderate; if the wind be ſoutherly, rain.
.50	2.	Rain, wind, thunder, hail, ſnow, &c.
.42	3.	Calm, but generally with heavy clouds.
.33	4.	Rain, wind, thunder, hail, ſnow.
.25	5.	Tolerably calm.
.17	6.	Heavy rain, or wind, thunder, hail, ſnow, &c.
.08	7.	Serene, though ſometimes fogs or miſt.
29	8.	Stormy; in winter, miſt.
.92	9.	Calm; in winter, thick fog.
.83	10.	Heavy ſtorms.
.75	11.	Calm.
.67	12.	Stormy.
.58	13.	Calm, but heavy clouds.
.50	14.	Half a hurricane.
.42	15.	Calm, with a great drift of ſcudding clouds.
28.33	16.	Violent hurricane.

Thus the barometer ſtood, the 12th December, 1747.

Theſe obſervations were made when the barometer was placed 25 feet above the level of the ſea or river waters.

When the mercury reſts at $\frac{1}{2}$ a degree, expect variable, or a mixture of that weather expreſſed by the degree above and below it.

Of

Of the Superiority of the Northern Hemisphere over the Southern, from the Rev. Mr. Jones's Physiological Disquisitions.

The ſuperiority of the northern hemiſphere of the world, above the ſouthern, is very manifeſt. It has more land, more ſun, more heat, more light, more arts, more ſenſe, more learning, more truth, more religion. The land of the ſouthern hemiſphere, that is, the land which lies on the other ſide of the equinoctial line, does not amount to one fourth part of what is found on the north ſide.

The ſun, by reaſon of the excentricity of the earth's orbit, and the ſituation of the aphelion, makes our ſummer eight days longer than the ſummer of the other hemiſphere; which, in the ſpace of four thouſand years, (for ſo long it is ſince any univerſal change has taken place in the earth) amounts to upwards of eighty ſeven years; and ſo much more ſun has this hemiſphere enjoyed than the other. What effects may have been ariſing gradually in all that time, we cannot aſcertain; but ſuch a cauſe cannot have been without it's effect: and I think it is allowed, that the temperature of the earth and atmoſphere, in the higheſt latitudes of the north, is much more mild and moderate than in the correſpondent latitudes of the ſouth. The dreary face of Staten-land, with the weather-beaten Cape of South-America, a climate ſo ſevere as ſcarcely to admit of any human inhabitants, is no nearer to the pole than the northern counties of England: but the difference in the atmoſphere, and in the aſpect of the earth, is almoſt incredible; and this is the more remarkable, becauſe there is no mountainous country betwixt that and the pole to account for the icy blaſts that prevail there.

But it is alſo further obſervable, that the northern hemiſphere is better provided for by night as well as by day. The ſtars of ſuperior magnitudes are much more numerous on this ſide the equinoctial than on the other: we have nine ſtars of the firſt magnitude, and they but four; and the ſtars of the Great Bear, ſo conſpicuous in this hemiſphere, have nothing to equal them about the other pole. When the ſun is remote from us in the winter, our longeſt nights are illuminated by the principal ſtars of the firmament; when the ſun enters Capricorn, there comes to the meridian, about midnight, the whole conſtellation of Orion, the brighteſt in the heavens, containing two ſtars of the firſt magnitude, four of the ſecond, and many others of inferior ſizes; and upon the meridian, or near it, there are four more ſtars of the firſt magnitude, Capella, Sirius, Procyon, and Aldebaran. No other portion of the heavens affords half ſo much illumination; and it is exactly accommodated to our midnight, when the nights are longeſt and darkeſt. If the mid-winter of the ſouthern hemiſphere be compared, the inferiority of the nocturnal illumination is wonderful.

Though it will carry us a little beyond the bounds of phyſics, the parallel is ſo glaring between the natural and intellectual ſuperiority of this part of the world, that your time will not be loſt while we reflect upon it. Here the arts of war and of peace have always flouriſhed; as if this part of the globe had been allotted to a ſuperior race of beings. Aſia and Europe, from the remoteſt times, have been the ſeats of ſcience, literature, eloquence, and military power; compared with which, the ſouthern regions have ever been, as we now find them, beggarly and barbarous; poſſeſſed by people ſtupid and inſenſible, illiterate, and incapable of learning. Where are the poets, the

the hiſtorians, the orators, the philoſophers, of the ſouthern world? We may as well ſearch for the ſciences amongſt the beaſts of the wilderneſs.

All the inventions, by which mankind have done honour to themſelves in every age, have been confined to this ſide of the world. Here the mathematical ſciences have flouriſhed; printing has been found out; gun-powder and fire-arms invented; navigation perfected; magnetiſm and electricity cultivated to the aſtoniſhment of the wiſeſt; and philoſophy extended by experimental inquiries of every kind. There would be no end, if we were to trace this compariſon through every improvement; for here we have every thing that can adorn human life, and there they have nothing.

But the difference is moſt conſpicuous, when we compare the north and ſouth in point of *religion;* to which, indeed, *that pre-eminence is owing on our ſide*, which has extended to every branch of ſocial civilization and intellectual improvement. It is notorious at this day, that arts and learning flouriſh to the higheſt degree, in thoſe countries only that are enlightened by chriſtianity, and no where ſo much as in this kingdom, where that religion is eſtabliſhed in it's pureſt form. May it long continue! and may we know our own felicity in the enjoyment of it! for religion is undoubtedly the ſun that gives light to the mind; the vital ſpirit that animates the human underſtanding to it's higheſt atchievements; though many have been indebted to it, without being ſenſible of their obligation, or without confeſſing it; and others have turned againſt it that light which they borrowed from itſelf.

The northern hemiſphere then, whatever preference it may have in a phyſical capacity, has been much more honoured by the ſuperior advantages of learning and religion: here knowledge firſt began

began to be diffuſed, and the world itſelf was firſt inhabited, in the fineſt climates of the earth, which are about the latitudes 36°, &c. north: here the church was firſt ſettled; and the Hebrew nation, riſing by degrees till the reign of Solomon, formed a wiſe, wealthy, and ſplendid kingdom, long before the powers of Greece and Rome were heard of: here the light of chriſtianity was afterwards manifeſted, and with it the lights of learning have been extended to parts where they were never known before, till both of them reached to the utmoſt boundaries of the weſt, in the once unknown regions of the Atlantic world.

CONCLUSION.

I have now finiſhed my courſe of Lectures, and have given you a general view of the principal phenomena in nature; nor have I been inattentive to the diſcoveries made therein by man. I have endeavoured to point out the abuſe that may be made of phyſical inquiries, and to guard you againſt the errors by which they may be perverted, and rendered a prop to ſupport the weak fabric of infidelity and falſehood. From theſe Lectures it evidently appears, "1ſt, That MAN is compoſed of two SUBSTANCES, of which one *perceives* without being *perceived* by the *ſenſes*; and the other is *perceived* without having any *perception* in itſelf. 2dly, That MAN, in his preſent ſtate, can perceive nothing more of the UNIVERSE than what is tranſmitted to him by his *organs*, whoſe faculties are very limited. 3dly, That there are evidently effects *perceptible* by MAN, which are occaſioned by BEINGS that he cannot *perceive*. 4thly, That MAN, deprived only of one ſenſe, *ſight*, would have been ignorant of the greater part of what he knows of the UNIVERSE, namely, of entire claſſes of BEINGS, and of the relations of theſe beings to each other,

other, and to thoſe with which he is acquainted. 5thly, and laſtly, By every rule of *analogy*, and from many phenomena, it is highly probable, that there exiſt many claſſes of BEINGS, related to each other, and to MAN, which he cannot in his preſent ſtate *perceive*."*

The ſpiritual powers of man are rouſed into action by the medium of the ſenſes. His underſtanding explains itſelf by the perceptions the ſenſes tranſmit; ſo that, notwithſtanding the extent of his powers, he can make no progreſs in matters higher than ſenſe, unleſs he take the *creation* for his leſſon, and the *omniſcient Creator* for his preceptor. It is therefore weak and perverſe in him, without the very elements of knowledge in his head, to deſert ſuch a wiſe and kind inſtructor, and then ſet up for *an independent diſcoverer*. Put the philoſopher to the trial, who pretends to know ſo much of a Deity without allowing him to diſcover himſelf and explain his own works, and you will ſoon ſee the wiſe man confounded by his own wiſdom. If this wanted proof, I need only mention the writings of Helvetius, Voltaire, Diderot, De la Metrie, and the whole ſchool of Condorcet.

In contradiction to theſe men, I have endeavoured to ſhew that philoſophy is illuſtrated, and juſt views of nature are exhibited by the ſacred writings. What indeed can we think of thoſe who would have us believe they credit the ſcriptures, while they take upon them to correct it's ſtile as not philoſophically juſt? who would have us believe, that He who holds all nature in his hand, does not know how to accommodate his doctrines to the capacities of the vulgar, without ſpeaking with philoſophical impropriety of his own works? Will they,

* De Luc, Lettres Phyſiques et Morales, tom. v. p. 11, p. 689.

they, indeed, teach Him to ſpeak, who gave a mouth to man, whoſe word was ſufficient to cauſe the mighty ſun to ſhine, and daily diffuſe his treaſures of light around the heavens, irradiating the ſhifting hemiſpheres of the revolving earth, and at whoſe command it is ſurrounded by the liquid air? Shall the writings of men have excellencies in our eyes, and his have no beauty, who hath meted out the heavens, who knoweth the ballancing of the clouds, and by whoſe knowledge the deeps are broken up?

Both HIS word and HIS works prove, that HE has employed and diſplayed infinite wiſdom, power, and goodneſs, in the creation of this univerſe; that HE has with ſtupendous artifice ſtored our globe with every thing neceſſary, not only for the ſupport, but for the felicity of man: all HIS works are ſtamped with the characters of the infinite perfections, and overflowing goodneſs of the AUTHOR. HE has given to man, and to him alone, a capacity to be entertained with the magnificence, the beauty, the harmony, and the order of the univerſe; and has ſo moulded his heart and ſpirit, as to make pleaſure attendant on admiration, and love and gratitude the neceſſary companions of the ſenſe of favours received.

Let us then praiſe the God of heaven, from whom we have received ſo much, whoſe mercy is extended over all.

Let every thing that hath breath praiſe him; and let man, the prieſt of the creation, offer up a ſacrifice of thankſgiving unto the MOST HIGH.

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REFERENCES to the PLATES of VOL. III.

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